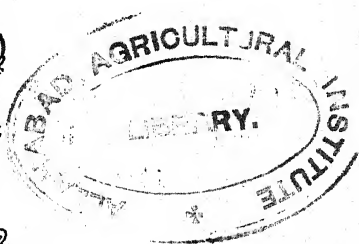


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Volume V



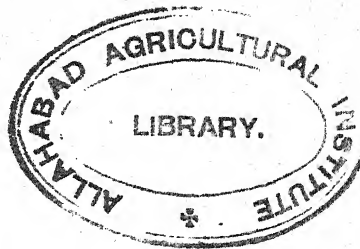
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THE GASES OF SWAMP RICE SOILS.

PART IV.

THE SOURCE OF THE GASEOUS SOIL NITROGEN

BY

W. H. HARRISON, D. Sc.,

Government Agricultural Chemist, Madras,

AND

P. A. SUBRAMANIA AIYER, B.A.,

Assistant to the Government Agricultural Chemist.

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INTRODUCTION.

IN a recent publication,¹ it was shown that considerable quantities of nitrogen gas were formed in swamp rice soils and that there were certain peculiar relationships between the incidence of this gas and the crop and green manure used which required elucidation.

The gas found in these soils is mainly a mixture of methane and nitrogen, but the proportion these gases bear to each other varies considerably with, and is dependent upon, several well defined factors. In uncropped soils, whether manured or unmanured, the methane greatly preponderates throughout the whole cultivation season. This also applies to cropped soils during the earlier period of growth, but about thirty days after the date of transplanting a rapid change sets in and the nitrogen becomes the preponderating constituent; and this relationship persists up to harvest time.² Consequently, the composition of the soil gases is modified by the presence or absence of a crop.

Furthermore, it was shown that there is more gas present in cropped than in uncropped soils,³ which means a considerably increased production of

¹ Harrison and Subramania. The Gases of Swamp Rice Soils. Part I, Their composition and relationship to the crop. *Mem., Dept. Agri., India, Chem. Ser.*, vol. III, no. 3.

² *Ibid.*, pp. 69-74.

³ *Ibid.*, p. 81.

nitrogen gas when the difference in composition of the gas is taken into consideration. In addition, it was found that the evolution of nitrogen was greatly influenced by the presence of green manure for there is approximately $2\frac{1}{2}$ times as much gas present in manured soils as in unmanured soils.¹ From this it follows that the production of nitrogen gas in swamp rice soils is mainly determined by two factors, one being the crop itself and the other the organic matter present in the soil and the green manure used.

These facts led to the tentative conclusion that in these soils there occurs a liberation of nitrogen gas from organic manures, which are therefore to this extent made of no direct agricultural value. This conclusion, although based upon field observations, is of dubious value, because the facts upon which it is formed deal only with the gases actually present in the soil at any particular time, for there must be a considerable escape of gas from these soils, and this may vary considerably under different conditions and be of such dimensions as to materially alter, if not even reverse, the above conclusion. It is obvious that this last factor must be evaluated if valid conclusions relating to the source of the nitrogen gas are to be drawn.

An attempt was made to measure the dimension of this factor under field conditions by inverting a large funnel filled with water over the surface of the soil, so as to trap any escaping gas.² Large volumes of gas were collected but as it was a mixture of oxygen and nitrogen, instead of methane and nitrogen, it was obvious that it had little, if any, connection with the soil gases proper. The source of the gas thus collected was traced to an organized film covering the surface of the soil which has been shown to possess the power of decomposing any carbon dioxide present in the irrigation water with the evolution of oxygen, and also to oxidize any methane and hydrogen as they escape from the soil to carbon dioxide and water. The carbon dioxide thus produced is in turn decomposed with the evolution of oxygen.³ The nitrogen found associated with the oxygen thus evolved from the surface of the soil appears to be derived by diffusion from the nitrogen dissolved in the irrigation water.

This being the case, any attempt to measure the volume of the nitrogen escaping from the soil is doomed to failure so long as this surface film is operative. Copper sulphate added to the irrigation water was found to kill, or render inoperative, the organisms composing the film, but great difficulties presented themselves when applied on the field scale. As an alternative

¹ *Ibid.*, p. 81.

² *Ibid.*, p. 75.

³ Harrison and Subramania. The Gases of Swamp Rice Soils. Part II. *Mem., Dept. Agri., India, Chem. Ser.*, vol. IV, no. 1.

potculture experiments were instituted¹ in which a very dilute solution of copper sulphate was used as irrigation water. This was found to greatly reduce the activity of the film and it was found possible to obtain some measurements of the volumes of the escaping gases under varying conditions of experiments which are detailed in the memoir previously referred to.

Experience has shown that these first experiments were of an unsatisfactory character but they brought out certain important facts which have since been confirmed. In the first place they distinctly showed that the escape of gas from uncropped soils was fairly uniform, whereas the amount escaping from cropped soils is practically *nil* until the crop reaches the heading stage, when a considerable evolution of gas occurs which continues up to harvest time. This was tentatively ascribed to the crop influencing the normal course of the soil fermentations. In the second place indications were obtained showing that more nitrogen was evolved from manured than from unmanured soils.

Notwithstanding this, it was felt that the evidence obtained was far from being satisfactory. In fact, in several respects, it materially conflicted with the deductions drawn from field observations, and consequently, these experiments have been continued under more rigorous and varied conditions. They have yielded results from which definite conclusions may be drawn and which offer an explanation of many of the peculiar facts previously noted which have hitherto remained unexplained.

One reason for the inconclusive results of the earlier experiments was due to the fact that the measurements and analyses were stopped immediately the ripening stage was reached and this limited the number and the scope of the observations. This error has been rectified and the records now given are carried up to the time of harvesting.

The most serious error, however, introduced into the earlier experiments was due to the action of the film in bringing about an evolution of nitrogen gas derived directly from the irrigation water and indirectly from the air. This action of the film is inhibited by the use of copper sulphate in the irrigation water, and this inhibition continues so long as soluble copper salts are present, but immediately this condition fails, owing to the precipitation of the copper, the activity of the film recommences and nitrogen, not derived from the soil, is evolved. In the earlier experiments the addition of copper sulphate was carried out, as was only natural, in a cautious manner and at long intervals, so that occasionally the film became active again leading to an increased evolution of nitrogen. Thus in one experiment a pot was yielding 0.07 cc.

¹ *ibid.*, Part I.

of oxygen and 0.3 cc. of nitrogen per day when it suddenly began to yield 3.6 cc. oxygen and 38.6 cc. nitrogen. On adding a further quantity of copper sulphate the evolution diminished to 0.3 cc. oxygen and 7.5 cc. nitrogen.

As any attempt therefore to measure the nitrogen evolution from the soil proper depends for its success upon the film being rendered inoperative throughout the whole course of the experiment, a stronger solution of copper sulphate has been used in the experiments to be described, and it has been given at more frequent intervals. So far as could be observed the increased dose had no harmful effect on the crop, but rather the reverse, for experiments instituted to test this point showed the copper to act as a crop stimulant.

There is no great difficulty experienced in controlling the action of the film in uncropped pots for any failure in this respect is at once made apparent by a greatly increased output of gas containing a considerable proportion of oxygen. In the case of cropped pots, however, difficulties present themselves for the oxygen formed by the film is absorbed by the roots, and the only result of the failure is to lead to an increased collection of nitrogen. In fact, in cropped pots it is possible for the film to be in an active condition without the fact being readily detected, and it is to this that the inconclusive results of our earlier experiments must be ascribed.

In the experiments now to be described particular attention was paid to the maintenance of a supply of copper sulphate in the surface water sufficient to inhibit the action of the film, and only by rigorously attending to this point has it been found possible to obtain concordant results. The experimental difficulties are enhanced by the fact that the surface water can only be conveniently changed at the time when the gases which have collected are removed for examination, so that the concentration of copper sulphate needs to be considerable in order to attain the desired result.

In all the experiments no drainage was arranged for with the object of limiting the amount of copper sulphate entering the soil to that drawn in under the action of transpiration, and possibly also a small amount by diffusion, so as to reduce to a minimum the danger of this substance affecting the normal soil fermentation. Concentrations varying from $\frac{1}{250,000}$ to $\frac{1}{5,000}$ have been used without in any way modifying the type of result obtained, and it therefore seems permissible to conclude that the amount which enters the soil under the experimental conditions does not materially affect the normal course of events in the soil.

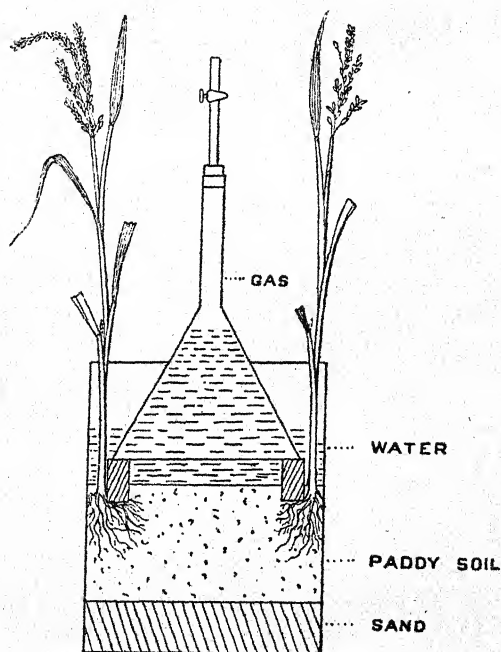
Notwithstanding these precautions, it is impossible to eliminate all traces of oxygen from the gases obtained, owing to the fact that they are collected

over water which, outside the funnel, is exposed to the air, and consequently, some diffusion must always occur. The amount thus diffusing can, however, be reduced to negligible proportions by using funnels for the collection of the gas of such a size that there is only just space enough between the edge of the funnel and the side of the pot for the growth of the seedlings. In these circumstances the surface of water exposed to the air is reduced to a minimum and the amount of oxygen which diffuses is consequently very small. When these conditions are fully satisfied the accumulation of oxygen is only from 0.05 to 0.2 cc. per day, and this amount may be looked upon as constituting a constant error for all the pots and be eliminated from further consideration. For this reason the oxygen values are not given in the sequel as they would serve no useful purpose and would unduly complicate the tables.

Apart from these considerations, the method of carrying out these experiments does not materially differ from that previously adopted by us. As all the experiments to be considered were carried out in a similar manner it will be as well to describe the method at this stage in order to prevent unnecessary repetition later.

The pots selected for the experiments were filled with the soil used to within about four inches from the brim. To those pots which were to receive manure the calculated amount was added and then all the pots were well puddled, distilled water being used for this purpose. In each pot four small wooden blocks were pushed into the soil to such a depth that they would support a funnel just clear of the surface of the soil. The seedlings were then planted around the circumference of such pots as were intended to carry a crop, care being taken to maintain the same number in each pot, and when

they were firmly established copper sulphate solution was gently poured on the surface of the soil until the pot was filled with the solution. The funnels, provided with good stopcocks in the shanks, were now placed in position and



filled by removing the air by suction. Thus any gas which subsequently escapes from the soil collects in the funnel from which it can be drawn and analysed at convenient intervals.

The experiments now under consideration have been carried out under very varying conditions and have extended over several seasons. Variation of soil, different varieties of paddy, mixtures of sand and soil, and even sand alone have been used. Each series of experiments has thrown considerable light on the immediate problem under consideration, but it is only by considering the results as a whole that definite conclusions can be drawn. Each type of experiment, however, serves to emphasize certain facts so that they will be considered individually in the first instance.

EXPERIMENTS WITH PADDY SOIL.

During the course of the past three years a large number of distinct pot-culture experiments have been carried out with paddy soils which have all yielded results of a very similar character and have led to the same general conclusions. This being the case, the results of two typical experiments only are recorded for the purpose of illustration.

In the first experiment the soil was obtained from a paddy field of the College Farm at the time of puddling, and it therefore contained a considerable proportion of comparatively fresh organic matter derived from the surface growth of weeds. This, however, is the natural condition of swamp paddy soils at the time of puddling so that this experiment probably approximates most nearly to natural conditions of any carried out.

The pots chosen for the experiment were of uniform size and were filled with the soil to within four inches of the rim. Three pots were manured with fresh *calotropis* leaf at the rate of 5,000 lb. to the acre, two being placed under crop and the third remaining uncropped. Of three corresponding unmanured pots two were cropped and the third left uncropped. After being thoroughly puddled the pots were allowed to remain untouched for seven days and then the seedlings were transplanted into them. When the seedlings were firmly established the surface was covered with copper sulphate solution and the collection of the escaping gas commenced. The paddy was a long-date type.

The scheme of experiment was, therefore, as follows :—

Two pots manured and cropped.

One pot manured but uncropped.

Two pots unmanured and cropped.

One pot unmanured and uncropped.

The results obtained are set out in Table I.

TABLE I.
Showing the evolution of Methane and Nitrogen from fresh soil.
cc. N. T. and P.
MANURED POTS.

Days collecting gas	CROPPED POT I						CROPPED POT II						UNCROPPED POT						REMARKS
	Nitrogen			Methane			Nitrogen			Methane			Nitrogen			Methane			
	cc. col- lected	Daily rate	Daily rate	cc. col- lected	Daily rate	Daily rate	cc. col- lected	Daily rate	Daily rate	cc. col- lected	Daily rate	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	
1st to 30th day	23.2	0.77		nil	nil		4.5	0.15		nil	nil		6.9	0.23	nil	nil			
30th to 59th "	2.0	0.07		nil	nil		5.5	0.19		nil	nil		56.4	1.94	0.9	0.03			
59th to 93rd "	1.9	0.06		nil	nil		5.9	0.17		nil	nil		34.0	1.40	1.5	0.04			
93rd to 110th "	33.8	1.99		5.1	0.30		37.8	2.22		5.6	0.33		13.7	0.80	1.8	0.10			
110th to 117th "	32.4	4.63		7.8	1.11		53.6	7.66		8.8	1.25		4.8	0.69	0.7	0.10			
117th to 124th "	22.1	3.16		6.8	0.97		30.6	4.37		9.7	1.38		5.6	0.40	0.8	0.03			
124th to 131st "	25.5	3.64		7.9	1.13		26.5	3.79		10.5	1.50		13.0	0.60	5.7	0.04			
131st to 142nd "	52.3	4.75		14.5	1.32		54.3	4.93		18.6	1.69		134.4	0.88					
142nd to 153rd "	25.5	2.32		5.5	0.50		32.3	2.93		8.0	0.73								
Totals and averages	218.7	1.42		47.6	0.31		251.0	1.64		61.2	0.40								

Heading commenced about the 100th day.

UNMANURED POTS.																		
1st to 31st day	8.0	0.26		nil	nil		6.3	0.20		nil	nil		17.7	0.57	nil	nil		
31st to 60th "	3.6	0.12		nil	nil		2.0	0.07		nil	nil		46.1	1.59	nil	nil		
60th to 94th "	3.8	0.11		nil	0.05		2.1	0.06		nil	nil		27.5	0.81	nil	nil		
94th to 111th "	6.2	0.36		0.9	0.06		5.5	0.32		0.9	0.07		5.3	0.31	0.8	0.01		
111th to 119th "	6.8	0.85		0.5	0.30		10.6	1.32		0.6	0.07		2.4	0.30	0.8	0.01		
119th to 133rd "	22.0	1.57		4.3	0.35		26.0	1.86		3.1	0.22		5.9	0.12	nil	nil		
133rd to 143rd "	22.5	2.25		3.5	0.15		13.2	1.32		1.4	0.14							
143rd to 159th "	15.6	0.97		2.4	0.07		9.0	0.56		0.6	0.04							
Totals and averages	88.5	0.56		11.6	0.07		74.7	0.47		6.6	0.04		104.9	0.66	0.8	0.01		

Heading commenced about the 100th day.

A consideration of these results from the general point of view shows, with regard to the manured pots, a much greater total evolution of nitrogen from cropped than from uncropped pots. At the same time the volume is greater from all the manured pots than from the corresponding unmanured pots. On the other hand, the volume given off from cropped unmanured pots is less than that from the corresponding uncropped pots. It is evident, therefore, that two of the deciding factors regulating the production of nitrogen gas, are the presence or absence of a crop and the amount of organic matter in the soil.

The most interesting conclusions to be drawn are, however, not those made between total volumes evolved, but those which emerge when the results are examined in detail. In Chart I, the numerical values obtained are plotted out in the form of addition curves showing the total amount of nitrogen evolved up to any particular date. A study of these curves shows that in uncropped pots the nitrogen evolution is most pronounced in the early stages, whereas, in cropped pots the reverse holds good, there being very little gas given off until the growing season is well advanced. It is further evident that this difference holds good whether the pots are manured or not, the manure, however, greatly affects the magnitude of the result. These relationships are perhaps brought out in a clearer manner in Chart II where the variations in the rates of evolution are plotted out as curves.

The main conclusions brought out by the above comparisons are:—

(1) *that the sequence of events is similar both in manured and unmanured soils and the only factor which affects the type of result obtained is the presence or absence of a crop in the soil, and (2) that the presence of green manure only affects the results in a quantitative manner, larger volumes of gas being then evolved.*

If the very probable assumption is made that the type of result obtained in uncropped pots represents the normal decomposition of organic matter in these soils, it becomes necessary to account for the action of the crop in (a) retarding the normal rate of nitrogen evolution in the earlier stages of growth, (b) in accelerating the normal rate in the later stages, and (c) causing an increased evolution of nitrogen in cropped manured soils compared with uncropped manured soils, whereas, the reverse is the case in unmanured soils. As the type of result is the same in cropped soils whether they are manured or not it would seem probable that the solution of the problems (a) and (b) would also offer a solution for (c).

One distinct fact is brought out by the experiments, namely, that in the early stages of growth comparatively little gas escapes from cropped soils compared to a fairly uniform evolution from uncropped ones. On the other hand, at about the time when the crop commences to run up for flowering

CHART I. Showing total evolution of Nitrogen to date from Paddy soils.

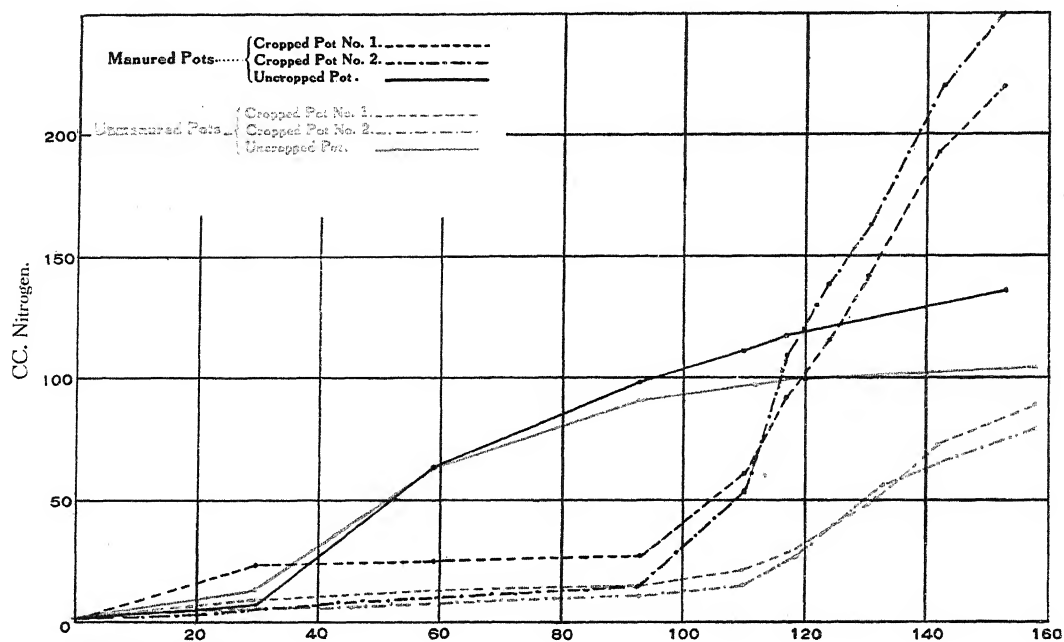


CHART II. Showing variations in rate of Nitrogen evolution from Paddy soil.

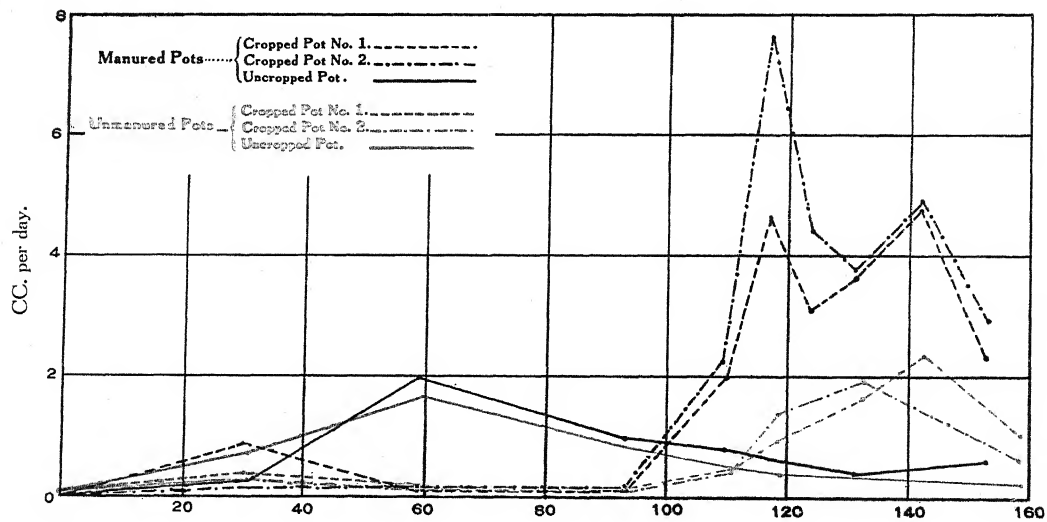


CHART III. Showing total evolution of Nitrogen to date from stored Paddy soil.

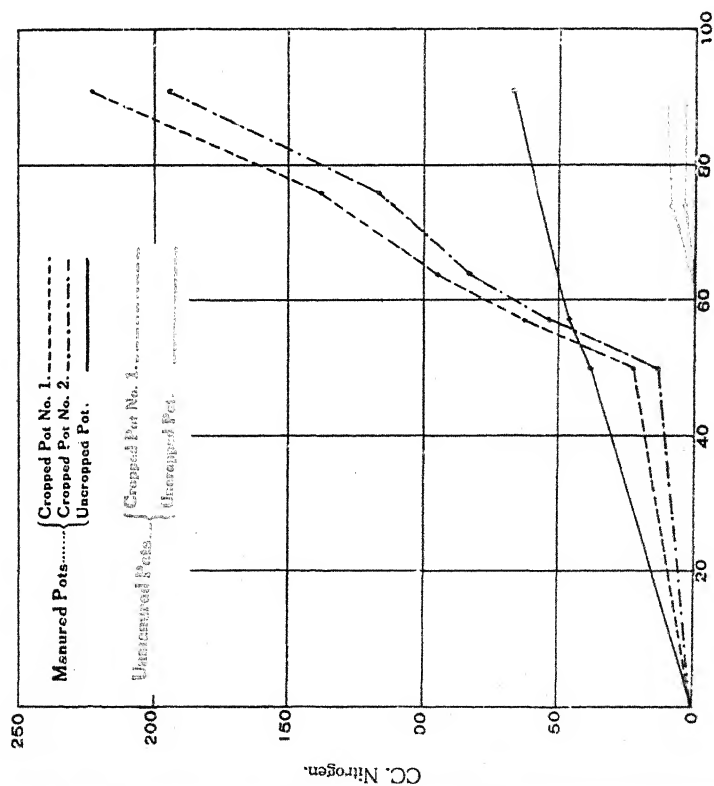
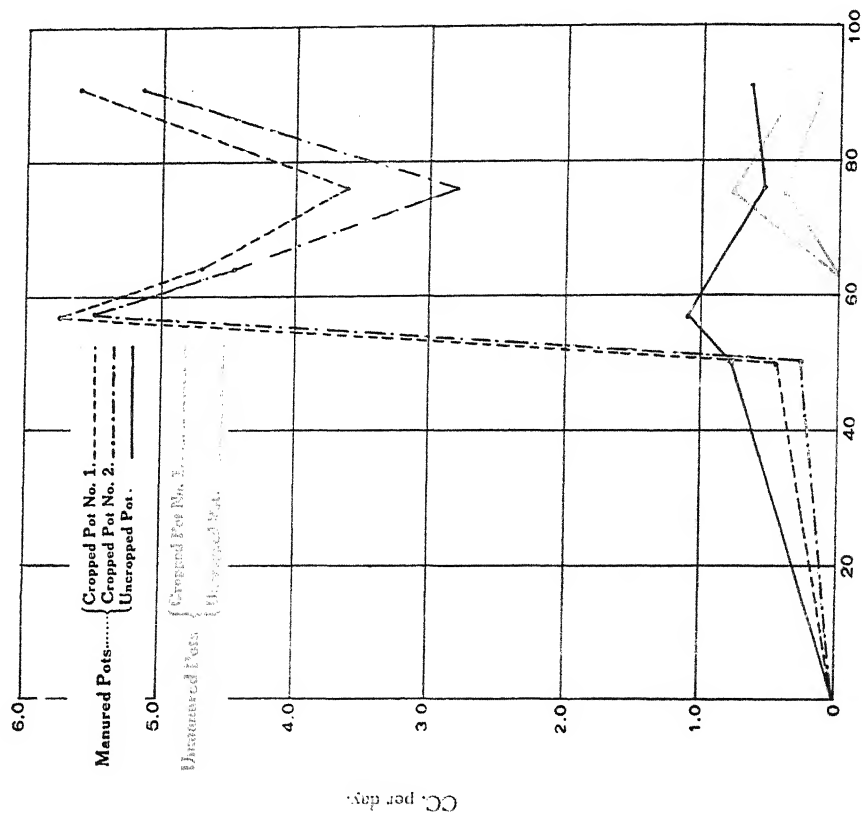


CHART IV. Showing variations in rates of Nitrogen evolution in stored soils.



there is a sudden and very considerable disengagement of gas which continues to harvest time, whereas, there is no such outburst in uncropped soils. This sudden evolution of nitrogen is accompanied by a similar disengagement of methane, so that it is justifiable to assume that the phenomenon is connected with the decomposition of organic matter.

In this experiment the volume of nitrogen given off by the uncropped unmanured pot is very nearly equal to that from the corresponding manured pot. In these uncropped pots, none of the nitrogen can be derived from the atmosphere through the agency of drainage, transpiration of a crop, or the activity of the surface film, and it is permissible to assume that its source is that of the organic matter contained in the soil. The particular soil used in this experiment was obtained from a paddy field at the time of puddling and contained a considerable proportion of vegetable detritus derived from the roots and debris of the preceding crop, and also the weeds and grasses raised during the dry season, so that the proportion of green manure added would only slightly increase the amount of organic nitrogen in the soil of the manured pot, and the volume of nitrogen evolved would not be greatly different from that of an unmanured pot, as is the case in this experiment.

If by any suitable means the proportion of decomposable organic matter in the soil could be greatly reduced, it would appear probable that comparatively little gas would be given off from unmanured soils and a greater differentiation produced in the experimental data which should result in making more prominent the effect of the crop and the manure. It was, therefore, decided to repeat the former experiment under conditions approximating to the above.

The immediate problem was to eliminate the easily decomposable organic matter from the soil without unduly affecting the biological and physical conditions. Burning the soil was out of the question as this would destroy all bacterial life and thus probably alter the normal course of fermentation. After considering the problem it was thought that the object aimed at could approximately be attained by storing the soil for some months before carrying out the experiment for, at tropical temperatures, organic matter of this type is quickly humified and brought into a comparatively stable state. This would also have the advantage of retaining sufficient nitrogen in the soil to feed the crop in the unmanured pot.

With the exception of using this stored soil instead of fresh soil and of using pure seed of a short date paddy strain, kindly supplied by Mr. Parnell, the Government Economic Botanist, the conditions of experiment remained the same as in the one just considered. The results of this experiment are given in Table II and the corresponding curves in Charts III and IV.

THE GASES OF SWAMP RICE SOILS

TABLE II.
Showing the evolution of Nitrogen from stored soil.

cc. N. T. and P.

MANURED POTS.

Days collecting gas	CROPPED POT I			CROPPED POT II			UNCROPPED POT		
	Nitrogen		Methane	Nitrogen		Methane	Nitrogen		Methane
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	Daily rate
1st to 50th day	22.7	0.45	5.8	0.12	13.9	0.28	39.1	0.07	0.78
50th to 57th "	40.2	5.74	18.3	2.61	38.4	5.49	7.8	2.34	1.11
57th to 64th "	32.0	4.70	17.1	2.44	31.0	4.43	}	1.70	0.57
64th to 76th "	43.0	3.58	22.9	1.91	33.5	2.79		0.80	0.64
76th to 91st "	84.3	5.62	28.9	1.92	77.4	5.16	9.6	1.11	0.03
Totals and averages	223.1	2.45	93.0	1.02	194.2	2.13	67.4	0.64	0.74
							0.5		...

UNMANURED POTS.

Days collecting gas	Nitrogen		Methane	Nitrogen		Methane	Nitrogen		Methane
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	Daily rate
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	Daily rate
1st to 64th day	nil	nil	nil	nil	...	...	nil	nil	nil
64th to 76th "	9.7	0.81	...	...	...	...	5.4	0.40	...
76th to 91st "	4.9	0.33	...	...	...	...	2.1	0.14	...
Totals and averages	14.6	...	...	...	...	...	7.5	...	...

This experiment shows that, so far as the manured pots are concerned, the reduction of the amount of decomposable organic matter had no effect upon the type of result obtained. There is still a very much larger evolution of nitrogen from the cropped pots than from the uncropped ones, but as in the previous experiment the greatest rate of evolution with the cropped pots is attained after the heading stage is reached, whereas, in uncropped pots the rate is of a much more uniform type. Compared with the results of the previous experiment, there is also a considerable reduction in the amount of gas given off from the uncropped pots, a result in accordance with the decrease in the amount of decomposable organic matter present.

The main point of interest, however, centres around the unmanured pots for, whether cropped or uncropped, no gas was evolved until the experiment was nearing a conclusion, and even then the volume was exceedingly small. It therefore appears justifiable to conclude that the volume of nitrogen gas produced in swamp paddy soils is dependent to a very considerable extent upon the quantity of decomposable organic matter present, a conclusion which receives considerable support in the sequel. If this is the case then the probability is that this nitrogen is derived from the organic matter which consequently is of less direct manurial value than has hitherto been considered to be the case. In this connection it must be made quite clear that the non-evolution of gas from any pot does not necessarily mean that no gas is being produced but only that there is not sufficient produced to cause it to be forced out of the soil. In fact the volume of gas held up in all paddy soils is considerable.

Considering as a whole the results obtained in these two experiments three main conclusions are to be drawn: (1) *that green manures and soil organic matter normally decompose under paddy soil conditions with the production of gaseous nitrogen, a considerable proportion of which ultimately escapes from the soil*; (2) *that in uncropped soils this nitrogen escapes at a fairly uniform rate whereas the presence of a crop prevents the escape of the gas during the early stages of growth and brings about a very considerable escape in the later stages*; and (3) *that there is a further production of nitrogen gas which is dependent upon the presence of a crop*.

If these conclusions are correct it now remains

- (1) to produce supplementary evidence in support of conclusion (1);
- (2) to determine the manner in which the crop causes the non-evolution of gas from the soil during the early stages of growth; and
- (3) to determine the source of the nitrogen gas produced through the action of the crop alone.

Further experiments were therefore instituted to determine, if possible, these points.

THE CAUSE OF THE RETARDATION IN THE RATE OF GASEOUS EVOLUTION.

In a previous memoir attention was drawn to the fact that the amount of gas escaping from cropped soils during the early stages of growth was comparatively small, whereas, during the later stages the position was reversed, but apart from drawing attention to the fact it was found impossible to offer a satisfactory explanation. This fact is now confirmed by the results of the experiments which have now been considered.

The cause of the phenomenon may be biological in character in that the crop may so affect the biological activities of the soil as to actually retard, if not even altogether change, the normal course of the decomposition of the organic matter present. There may also be during the earlier stages of growth such an absorption of nitrogenous substances by the crop as to materially lessen the normal gas production.

Apart from probable biological causes there is a possible one of a purely physical character. These paddy soils are of a very heavy type and are characterized by the large proportion of the finest grades of soil particles they contain. This being the case it is possible that the fine roots of the crop, which normally are found mainly in close proximity to the surface of the soil, would, in conjunction with the fine soil, form a layer offering a much greater resistance to the passage of the gases than would be the case in uncropped soils. In these circumstances, the gaseous products of the fermentation would be held up in the soil for a longer period and an apparent retardation of the fermentation produced.

To decide between the merits of these theories the following experiments were instituted. If the physical theory were correct then by using a coarse soil, the escape of the gas would be facilitated and the phenomenon of retardation during the early stages of the growth of the crop would become less prominent or even entirely disappear. On the other hand, if this coarse soil consisted of a mixture of sand and paddy soil the biological relationships would not be materially altered and if these were the determining factors the phenomenon would persist under the new conditions.

In carrying out these experiments the soil used in the pot cultures consisted of a mixture of four parts of clean river sand and one part of paddy soil obtained in a perfectly fresh condition from the fields of the Agricultural College, Coimbatore. Apart from this the experiments were merely replicas of the ones previously discussed and so call for no further comment. The results obtained are as follows:—

TABLE III.
Showing evolution of Nitrogen and Methane from mixture of sand and fresh soil.

A. MANURED POTS.

Days collecting gas	CROPPED POT I				CROPPED POT II				UNCROPPED POT			
	Nitrogen		Methane		Nitrogen		Methane		Nitrogen		Methane	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 14th day	6.7	0.48	nil	nil	7.3	0.52	nil	nil	11.6	0.41	1.0	0.04
14th to 28th "	23.1	1.65	0.9	0.06	38.1	2.72	1.4	0.10	4.5	0.32	nil	nil
28th to 42nd "	19.6	1.40	nil	nil	23.3	1.74	nil	nil	6.1	0.44	nil	nil
42nd to 56th "	22.2	1.58	0.3	0.02	18.3	1.31	nil	nil	7.8	0.56	0.3	0.02
56th to 70th "	32.8	2.34	5.0	0.36	23.1	1.65	nil	0.31	5.8	0.41	nil	nil
70th to 84th "	41.5	2.96	10.1	0.72	45.2	3.22	4.3	0.78	4.2	0.32	0.4	0.03
84th to 97th "	60.4	4.65	16.4	1.26	40.5	3.11	10.1	1.41	4.2	0.32	0.1	0.01
97th to 105th "	42.8	5.35	17.7	2.21	31.6	3.95	11.3	2.40	4.2	0.32	0.1	0.01
105th to 110th "	30.9	6.18	19.5	3.90	22.5	4.50	12.0	2.40	4.2	0.32	0.1	0.01
Totals and averages ..	280.0	2.51	69.9	0.63	249.9	2.35	39.1	0.35	41.2	0.40	1.8	0.01

B. UNMANURED POTS.

Days collecting gas	Nitrogen		Methane		Nitrogen		Methane		Nitrogen		Methane	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 14th day	4.6	0.33	nil	nil	5.0	0.36	nil	nil	7.8	0.28	nil	nil
14th to 28th "	7.5	0.54	0.2	0.01	7.8	0.56	nil	nil	9.8	0.20	nil	nil
28th to 42nd "	11.9	0.85	0.4	0.03	10.3	0.74	0.3	0.02	1.7	0.12	nil	nil
42nd to 56th "	12.0	0.86	nil	nil	10.5	0.75	nil	nil	1.1	0.08	nil	nil
56th to 70th "	13.3	0.95	nil	nil	11.7	0.84	nil	nil	0.9	0.06	nil	nil
70th to 84th "	10.7	0.77	0.7	0.05	11.9	0.85	0.5	0.04	3.5	0.27	nil	nil
84th to 97th "	13.4	1.03	1.7	0.13	12.1	0.98	1.0	0.07	2.8	0.25	nil	nil
97th to 108th "	12.6	1.14	3.1	0.28	12.0	1.09	2.0	0.18	20.6	0.19	nil	nil
Totals and averages ..	86.0	0.80	6.1	0.05	81.3	0.75	3.8	0.03	20.6	0.19	nil	nil

A comparison of these results with those detailed in the preceding section of this memoir distinctly points to the occurrence of a different sequence of events. The phenomenon of the non-evolution of gas in the early stages of growth has disappeared and in its place there is a greater evolution of gas from the cropped pots than from the uncropped pots throughout the whole course of experiment. At the same time the irregularity previously noticed with regard to the unmanured pots, in that less total gas is given off from the cropped than from the uncropped pots has vanished, and they fall into line with the manured pots. (See Charts V and VI.) From this it is concluded that similar factors are at play whether the soil is manured or not, but the fact that much more gas is evolved from manured than from unmanured pots shows that the intensity of the action is largely dependent upon the amount of easily decomposable organic matter present.

It is also noteworthy that, whereas the rate of evolution of nitrogen from uncropped pots is fairly uniform that from cropped pots shows, in general, an increasing rate with the age of the crop. This fact serves to emphasize the conclusion previously drawn that there is a considerable evolution of nitrogen due to the presence of a crop and which is independent of the presence of organic matter in the soil or manure.

The main result of this experiment has been, however, to clearly demonstrate that the non-evolution of gas in the early stages of the growth of the crop under natural conditions is mainly a purely physical phenomenon and not a biological one. It is due to superficial root development of paddy acting in conjunction with the very fine textured soils and thus forming a surface layer which offers greater resistance to the passage of the gases than occurs in uncropped soils. These gases are thus trapped beneath the surface of the soil and the phenomenon of retarded evolution of gas is produced. This is in agreement with field observations, for, in uncropped soils the gases are fairly evenly distributed throughout the soil, whereas, in cropped soils the main accumulation of gas is always found in those areas which contain the roots of the crop, and comparatively little is found in any bare patches.

This trapping of the soil gases in close proximity to the organized surface film is one more factor leading to their more complete utilization for the aeration of the roots and at the same time it offers a very simple explanation of that curious change in composition of the soil gases under the action of a crop which has been referred to in a previous publication. These points will be fully discussed in the sequel.

In this experiment fresh soil was used which introduced a quantity of organic matter apart from that contained in the green manure added.

CHART V. Showing total evolution of Nitrogen to date from a mixture of sand and fresh Paddy soil.

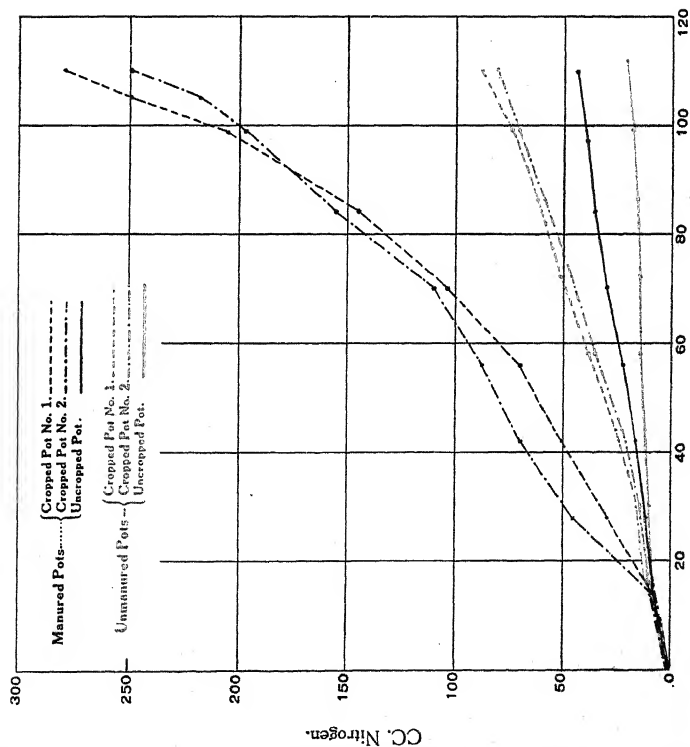


CHART VI. Showing variations in rate of Nitrogen evolution from mixture of sand and fresh soil.

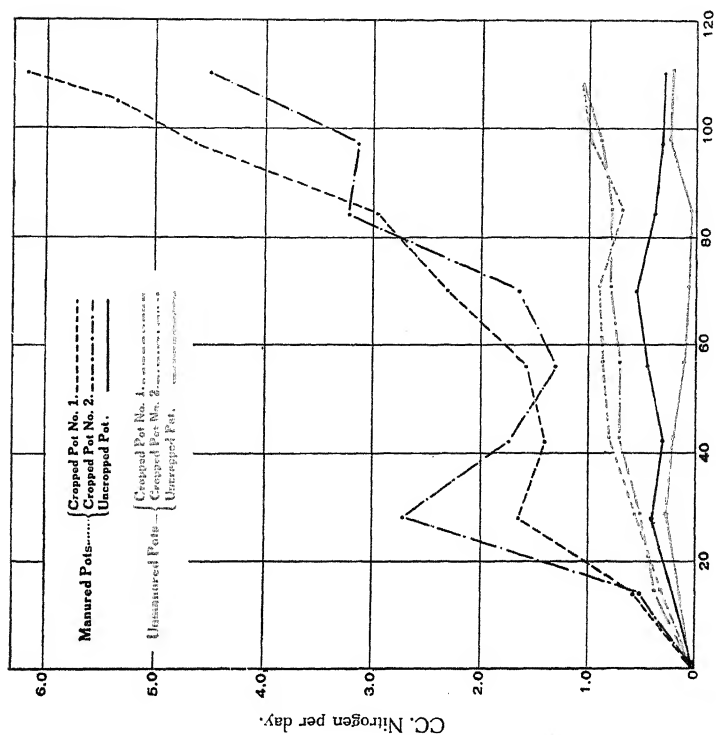


CHART VII. Showing total evolution of Nitrogen to date from mixtures of sand and stored soil.

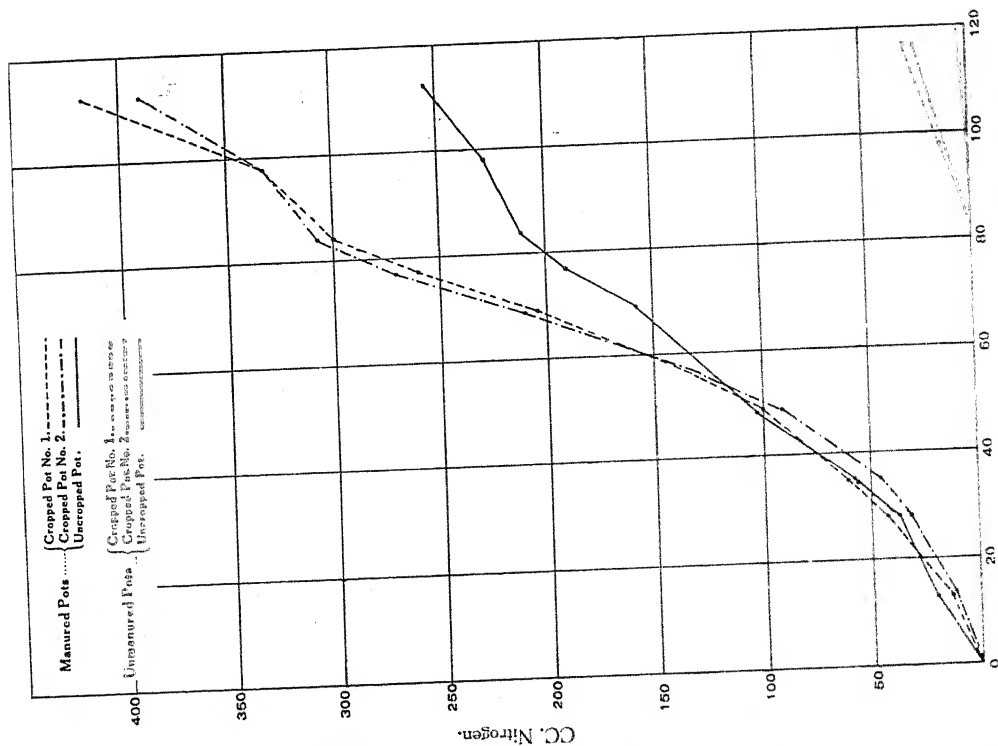
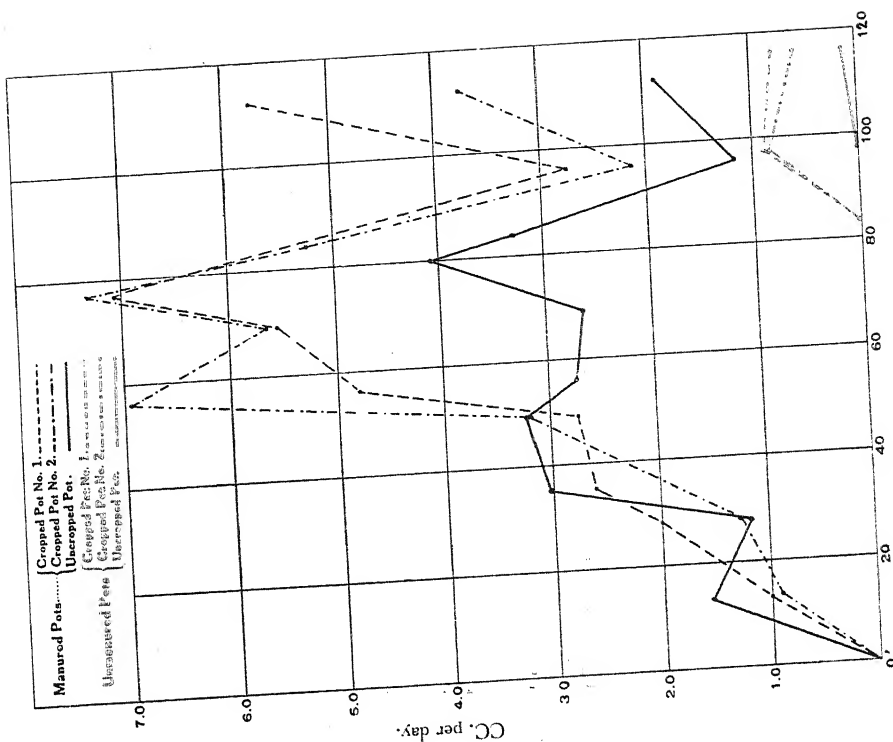


CHART VIII. Showing variations in the rates of Nitrogen evolution from mixtures of sand and stored soil.



Following the same line of argument adopted in the preceding section it was deemed advisable to repeat this experiment using a mixture of sand and stored soil, thus reducing the amount of decomposable organic matter present to that introduced solely by the green manure. It was thus hoped to obtain clearer evidence regarding the relationship between the amount of organic matter present in the soil and the quantity of nitrogen evolved. There was also a probability that the action of the crop in bringing about a nitrogen evolution would also be made more prominent.

Apart from the use of stored soil this experiment only differed from the preceding one in the employment of a strain of pure seed. The results are given in Table IV and the corresponding curves in Charts VII and VIII.

This experiment serves to emphasize the conclusion previously drawn that the retardation of the normal rate of gas evolution is chiefly due to physical causes and not biological ones. In addition it demonstrates the fact that in soils containing little organic matter there is no evolution of nitrogen until the later stages, when the influence of the crop becomes most apparent. In the manured pots the nitrogen evolution is practically the same from cropped or uncropped ones, until the crop has reached half growth, and then there is an increased rate of evolution from the cropped pots only. It may be concluded from this that the crop has little influence upon the course of the normal decomposition of organic matter in these soils and consequently the greatly increased output of nitrogen gas from cropped soils is largely due to the crop itself.

Taking this series of experiments as a whole the conclusions brought out are :—

1. *That organic matter when decomposing in these soils liberates considerable quantities of nitrogen gas and that this decomposition is not materially modified by the presence of a crop.*
2. *That the crop in some way or another is connected with the production of a further quantity of nitrogen and methane and that this factor is most prominent during the later stages of growth.*
3. *That the non-evolution of gas from cropped soils during the early stages of growth and under normal conditions is a purely physical phenomenon and not a biological one, and is due to the surface development of the roots forming, in conjunction with the fine textured soil, a layer offering increased resistance to the passage of the gases.*

TABLE IV.
Showing evolution of Nitrogen and Methane from mixtures of sand and stored soils.
A. MANURED POTS.

Dates of Collection	CROPPED POT I			CROPPED POT II			UNCROPPED POT		
	N		CH ₄	N		CH ₄	N		CH ₄
	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected
1st to 13th day	12.8	0.99	nil	12.5	0.96	0.04	20.2	1.55	9.8
13th to 28th "	29.9	1.99	3.8	19.0	1.27	0.10	17.1	1.14	17.1
28th to 35th "	18.1	2.58	6.1	14.3	2.04	0.31	21.2	3.02	23.7
35th to 49th "	38.5	2.75	8.4	44.8	3.20	0.50	45.1	3.22	42.0
49th to 56th "	33.7	4.81	16.8	48.6	6.94	2.15	19.3	2.75	18.8
56th to 69th "	72.2	5.55	27.2	73.5	5.65	1.28	34.6	2.66	17.4
69th to 77th "	56.5	7.06	26.3	59.0	7.38	2.68	32.6	4.08	7.1
77th to 84th "	37.8	6.40	23.2	36.7	5.24	1.73	23.0	3.29	11.7
84th to 98th "	38.6	2.76	16.4	29.6	2.11	0.34	16.7	1.19	11.0
98th to 112th "	80.3	5.73	26.0	52.2	3.73	0.91	26.9	1.92	12.7
Totals and averages ...	418.4	3.74	154.2	390.2	3.48	0.84	256.7	2.29	171.3

B. UNMANURED POTS.

Dates of Collection	N		CH ₄	N		CH ₄	N		CH ₄
	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected	Daily rate	cc. col-lected
1st to 84th day	...	No gas	...	...	...	...	...	No gas	...
84th to 98th "	12.5	0.89	nil	12.2	.87	nil	...	No gas	...
98th to 117th "	15.1	0.79	0.6	11.0	.38	nil	2.6	...	nil
Totals and averages ...	27.6	0.23	0.6	23.2	0.20	nil	2.6	0.02	nil

THE CAUSE OF THE PRODUCTION OF NITROGEN GAS UNDER THE ACTION OF THE CROP.

The final point remaining for elucidation is the reason for the production of nitrogen gas under the action of the crop as distinct from that caused by the decomposition of the organic matter present in the soil and the green manure.

Field observations point to the solution of this lying in the fact that under normal conditions there are always found throughout the soil a large number of dead and decaying paddy roots even where the crop is in a perfectly vigorous and healthy condition. As organic matter has been shown to lead to a disengagement of nitrogen gas during the process of its decomposition in paddy soils it seems permissible to assume that the decomposition of these roots would likewise have the same effect. This assumption would also account for this factor appearing most prominent during the later stages of growth when root development has reached a maximum.

To test the theory an experiment was carried out in sand culture only, the nutrients being supplied by adding 1.5 litres of the following solution to each pot :—

6.0	grams	Ammonium phosphate.
1.8	„	K_2SO_4
1.5	„	$MgSO_4$
1.5	„	$NaCl$.
2	drops	5% $FeCl_3$ solution.
600	cc.	water.

A further quantity equal to 6.5 litres of distilled water was also added so as to fully saturate the sand with water.

In addition 10 grams of calcium carbonate were mixed with the sand. Although some difficulty was experienced in getting the seedlings well established, once this occurred vigorous growth ensued and the resulting crop was very much better than those obtained in the preceding experiment with mixtures of sand and soil. Under the conditions of this experiment no organic matter was present in the soil other than that produced by the development of the roots of the crop. The production of the nitrogen gas by the decomposition of green manure was thus eliminated and consequently any production of nitrogen and methane could with certainty be referred to the decomposition of the roots. Unfortunately, owing to difficulties in procuring apparatus it was found impossible to use the same sized funnel in all cases so that although one cropped pot and one uncropped pot were large in size

and held funnels twelve inches in diameter, the remaining cropped pot was somewhat smaller in size so as to accommodate a ten-inch funnel. The results obtained are therefore not strictly comparable in a quantitative sense, but they are of the same type and permit of the same conclusions being drawn.

In addition to the above an experiment was also carried out with green manure in place of ammonium sulphate. To each pot was added 80 grams *calotropis* leaves and 10 grams K_2SO_4 , 10 grams pure basic super and 10 grams $CaCO_3$. This experiment was intended to give extra evidence in favour of the physical retention of the gases under normal conditions, but mainly to help in forming a decision regarding the period during which the gas evolution due solely to crop chiefly occurs. The results obtained, however, did not fulfil expectations owing to the very poor crop raised. The results of both experiments are given in Table V and the corresponding curves in Charts IX and X.

CHART IX. Showing total evolution of Nitrogen to date from the sand cultures.

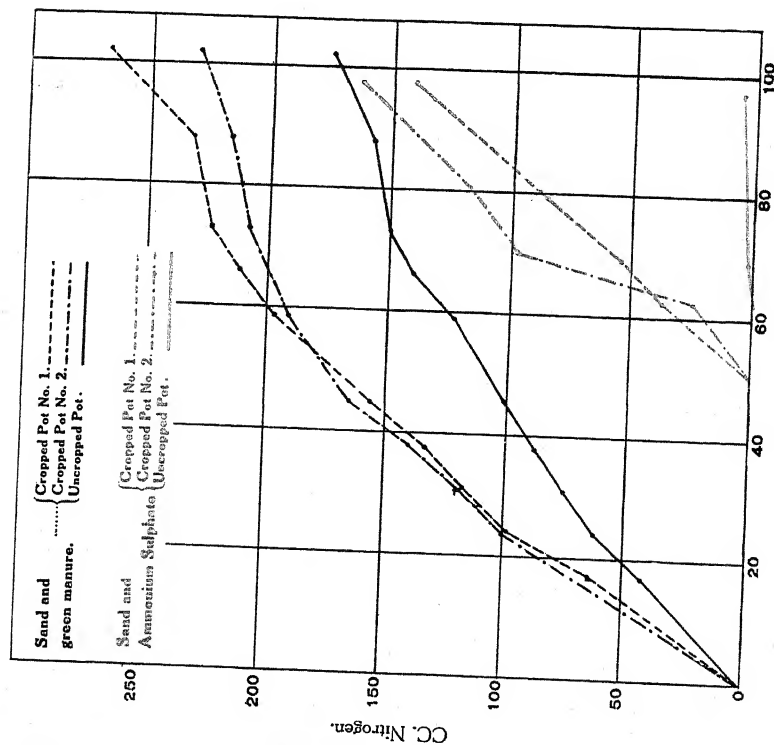


CHART X. Showing variations in the rate of Nitrogen evolution from the sand cultures.

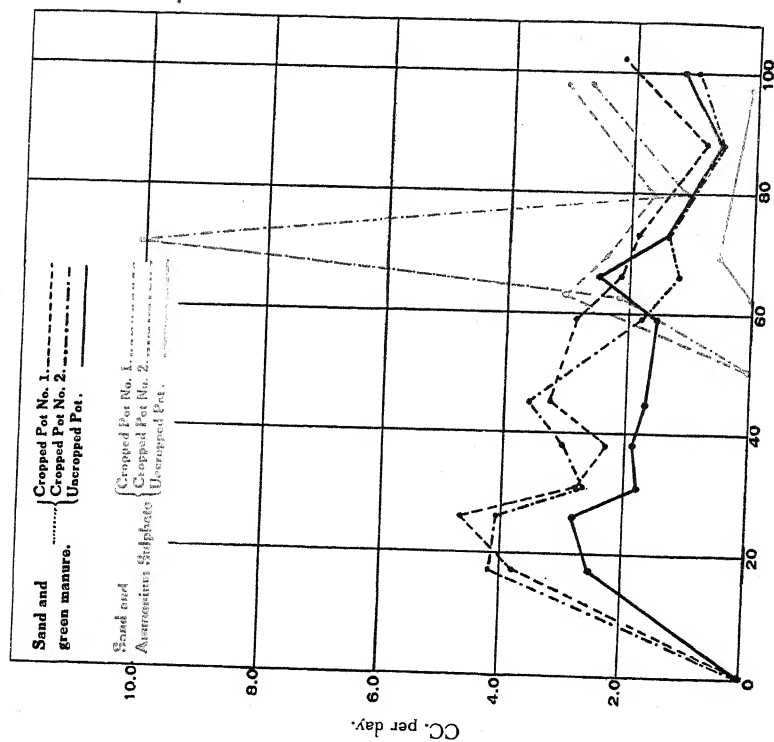


TABLE V.
Showing evolution of Nitrogen and Methane in sand cultures.

A. SAND AND GREEN MANURE.

No. of days collecting	CROPPED POT I				CROPPED POT II				UNCROPPED POT			
	N		CH ₄		N		CH ₄		N		CH ₄	
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate
1st to 17th day	64.2	3.78	25.6	1.50	71.5	4.21	42.3	2.49	43.0	2.53	23.6	1.39
17th " 24th "	33.1	4.73	17.5	2.50	28.4	4.06	27.7	3.95	19.9	2.84	19.6	2.80
24th " 31st "	19.9	2.84	7.2	1.03	18.7	2.67	9.9	1.41	12.5	1.79	12.5	1.79
31st " 38th "	16.1	2.30	4.8	0.68	21.4	3.05	8.9	1.27	13.1	1.87	13.0	1.85
38th " 45th "	22.9	3.27	8.3	1.18	25.3	3.61	10.1	1.44	12.0	1.71	9.2	1.31
45th " 52th "	40.1	2.86	nil	nil	25.0	1.79	9.3	0.16	22.0	1.57	23.9	1.71
52th " 59th "	15.1	2.15	3.4	0.48	8.4	1.20	3.1	0.44	17.8	2.54	10.3	1.47
59th " 66th "	12.9	1.84	2.4	0.34	9.4	1.34	2.8	0.40	9.7	1.38	7.1	1.01
66th " 73rd "	12.2	0.81	1.7	0.11	7.9	0.53	1.0	0.07	7.9	0.53	5.5	0.37
73rd " 88th "	30.5	2.18	3.3	0.24	14.2	1.01	2.1	0.15	17.5	1.25	10.4	0.74
88th " 102nd "												
Totals and averages ...	267.0	2.62	74.2	0.73	230.2	2.26	110.2	1.08	175.4	1.72	135.1	1.32

B. SAND AND AMMONIUM SULPHATE.

No. of days collecting	N		CH ₄		N		CH ₄		N		CH ₄	
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate
	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate	cc. col- lected	Daily rate
1st to 50th day	38.9	3.24	4.1	0.34	25.1	2.09	nil	nil	...	No gas	...	...
50th " 62nd "	16.4	2.34	2.9	0.41	70.6	10.08	0.7	0.1	...	No gas	...	...
62nd " 69th "	21.9	1.68	4.4	0.23	20.0	1.05	nil	0.15	3.9	0.55	nil	...
69th " 79th "	56.6	3.14	6.3	0.35	49.8	2.76	2.7	...	2.8	0.08	nil	...
79th " 97th "												
Totals and averages ...	143.8	1.48	17.7	0.18	165.5	1.70	3.4	0.03	6.7	0.07	nil	nil

The result of the experiment with sand and purely mineral manures shows clearly the cause of the disengagement of nitrogen gas under the influence of the crop. The production of the gas in the uncropped pot is practically *nil* showing that there is no appreciable formation of nitrogen gas when organic matter is entirely absent and that the comparatively large evolution of nitrogen from the corresponding cropped pots is solely due to the influence of the crop. The gas collected from the latter is associated with methane, which could only be produced through the fermentation of organic matter, and as the only organic matter present in the soil of these pots consists of the roots of the crop it appears obvious that this disengagement of gaseous nitrogen under the influence of the crop is directly associated with the destruction of, at least, some of the roots. It is also a matter of general field observation that the paddy plant is continually putting out new roots and that many of the older roots are in a state of decay and consequently it is permissible to conclude that *a considerable proportion of the nitrogen gas which escapes from the soil of cropped paddy soils is liberated through the decomposition of some of the roots of the crop and has no connection with the decomposition of green manures or of soil organic matter.* The fact that gas was only obtained from these pots towards the final stages of the experiment also leads to the further conclusion that this phenomenon is most prominent during the later stages of growth.

Additional evidence that root decomposition is responsible for nitrogen evolution is obtained by collecting the gas from pots after the crop has been harvested. Very considerable volumes of both nitrogen and methane are obtained from cropped pots, whether manured or unmanured, whereas, the uncropped pots maintained a low rate of evolution. Here the production of nitrogen gas can only be due to root decomposition. The following table illustrates this point:—

TABLE VI.
Showing evolution of Nitrogen after the harvest has been taken.

	NITROGEN COLLECTED DURING GROWING SEASON			NITROGEN COLLECTED AFTER HARVEST		
	Number of days	Volume collected	Rate	Number of days	Volume collected	Rate
		cc.	cc.		cc.	cc.
Cropped and manured Pot I ..	153	225.7	1.42	24	101.7	4.2
Cropped and manured Pot II ...	153	251.0	1.64	24	130.7	5.4
Manured and uncropped ..	153	134.4	0.88	24	8.2	0.34
Cropped and unmanured Pot I ..	159	88.5	0.56	23	90.0	3.9
Cropped and unmanured Pot II ..	159	74.7	0.47	19	45.4	2.4
Unmanured and uncropped ..	159	104.9	0.66	23	3.1	0.13

Turning now to the pots containing sand and green manure it must be borne clearly in mind that the crop produced was exceedingly poor being, in fact, only about one-tenth of that obtained from pots containing soil and green manure and one-eighth that from a similar pot containing sand and ammonium sulphate only. This being the case the effect of the crop is reduced to a minimum in this experiment and a comparison of the data obtained from the cropped and the uncropped pots should yield more nearly equal values than in the cases previously considered where the cropping is much better. The results obtained show this to be the case and consequently this experiment is mainly concerned with the production of nitrogen gas through the decomposition of green manure and soil organic matter.

That the nitrogen in this case is mainly derived from the organic matter present is shown by comparing the results with those from the sand and ammonium sulphate series. Further, as the greater portion of this nitrogen is given off during the earlier stages of the experiment, it may be concluded that this phenomenon is most prominent during the earlier portion of the cropping season.

This experiment with sand and green manure thus emphasizes the conclusion previously arrived at that *a considerable proportion of the nitrogen gas which escapes from paddy soils is produced through the fermentation of green manure or soil organic matter.*

GENERAL SUMMARY AND DISCUSSION OF RESULTS.

I. It has been demonstrated that a very considerable proportion of the gaseous nitrogen normally found in swamp paddy soils is produced through the decomposition of organic matter, a view which is supported by Leather's estimate of the nitrogen-argon ratio of these gases.¹

The nitrogen gas thus liberated is derived from two distinct sources, namely, (a) from the decomposable organic matter of the soil or of the green manure used, and (b) from a certain proportion of the roots of the crop which die and subsequently decompose.

The production of gaseous nitrogen from soil organic matter and green manure persists throughout the growing season, but is most prominent during the earlier period, whereas, that derived from root decomposition is most prominent during the later stages of growth and persists after harvest time.

II. There is no evidence forthcoming to show that the crop interferes with, or materially alters, the normal course of the fermentation of the soil

¹ Leather, J. W. Soil Gases. *Mem. Dept. Agri, India, Chem. Ser.* vol. IV. no. 3, p. 113.

organic matter and green manure, in fact the balance of evidence is distinctly against this theory.

III. Under normal conditions in uncropped soils the nitrogen gas thus produced escapes from the soil into the air at a fairly uniform rate. On the other hand, that produced in cropped soils does not escape in any quantity until about the time when the plant is running up for flower. At this stage a very marked escape of gas occurs which continues up to and past harvest time.

This irregularity in the escape of the soil gases from cropped paddy soils is a purely physical phenomenon, and is caused by the roots of the crop forming, in conjunction with fine soil, a surface layer which resists the passage of the gases. The gas is thus trapped and retained in the soil until the accumulation is sufficient to cause a passage to be forced, or until the decay of some of the roots opens out such a passage.

IV. In a previous publication attention has been called to the curious change in the composition of the soil gases under the action of a paddy crop. It has been shown that the composition remains fairly uniform in uncropped soils and that methane is present in a much larger proportion than the nitrogen. This is also the case in cropped soils up to about thirty days after transplanting, but after this stage a rapid change occurs which results in the nitrogen predominating, and this continues up to harvest time. No reasonable explanation has been available hitherto to account for this change, but the facts now brought forward throw a new light on the phenomenon and co-ordinate it with the previous work relating to the utilization of the soil gases for the aeration of the roots of the crop.

In these poorly drained soils a very large proportion of the roots of the paddy are either on, or in very close proximity to, the surface of the soil, and, as it has been pointed out, they prevent the soil gases from escaping readily into the air. The effect of thus trapping the gases is to concentrate them in the soil in very close proximity to the organised surface film, which has been shown to possess the power of oxidizing methane and hydrogen to carbon dioxide and water, and also to decompose the carbon dioxide thus produced with the liberation of pure oxygen. The oxygen thus produced is then available for the aeration of the roots.

The gases present in freshly manured and puddled soils contain about 70 per cent. of methane and 30 per cent. of nitrogen which readily escapes from uncropped soil. If this also occurred in cropped soils during the early stages of growth, when the demand for the root aeration is relatively small,

there would subsequently ensue a considerable reduction in the efficiency of the root aeration. This, however, is not the case and *the action of the roots in retarding the escape of the soil gases conserves the methane and thus makes it available for the later stages of growth when the plant is more mature and the demand for root aeration greater.* This action of the roots of the crop may, therefore, be looked upon as a natural provision for the conservation of methane.

Further, the gases thus imprisoned are held in close proximity to the surface film and consequently diffusion of the methane and its subsequent oxidation will slowly occur. As the irrigation water entering the soil already contains in solution a considerable amount of nitrogen, there will not be the same tendency for this gas to diffuse as is the case with methane, and therefore the sequence of events will be for methane to gradually disappear and the nitrogen to accumulate, so that in time the latter gas will preponderate. The result will be that a change in composition of the soil gases will occur such as has been shown to take place in cropped soils. In uncropped soils, on the other hand, the escape of the soil gases is not retarded and the nitrogen and methane will reach the surface film together and the former escape; thus the composition of the soil gases will not materially alter.

The physical retention of the soil gases through the action of the roots of the crop, taken in conjunction with the oxidizing action of the film, offers a simple and complete explanation of the change in composition of the soil gases under the action of the crop.

Further evidence in support of the above is adduced from the fact that hydrogen, one oxidizable constituent of the soil gases in uncropped soils, is practically non-existent in cropped soil gases, just as the methane, the other oxidizable constituent of the soil gases, is reduced in proportion.

V. The liberation of nitrogen gas owing to the decay of some of the roots is no doubt due to some extent to the decomposition of the nitrogenous organic matter contained in them under swamp soil conditions, but whether or not the source of the whole of the nitrogen thus produced can be ascribed to this cause is a debatable point. The older portions of paddy roots contain a certain amount of gas which would escape when the roots decay, and it, therefore, seems very probable that some of the nitrogen liberated under the action of the crop may have an atmospheric source. Some support is given to this from Leather's analyses of paddy soil gases by which he demonstrated the presence of argon in them. The nitrogen-argon ratio obtained was small, much smaller in fact than the ratio required on the assumption that the nitrogen was derived from the atmospheric gases dissolved in the irrigation

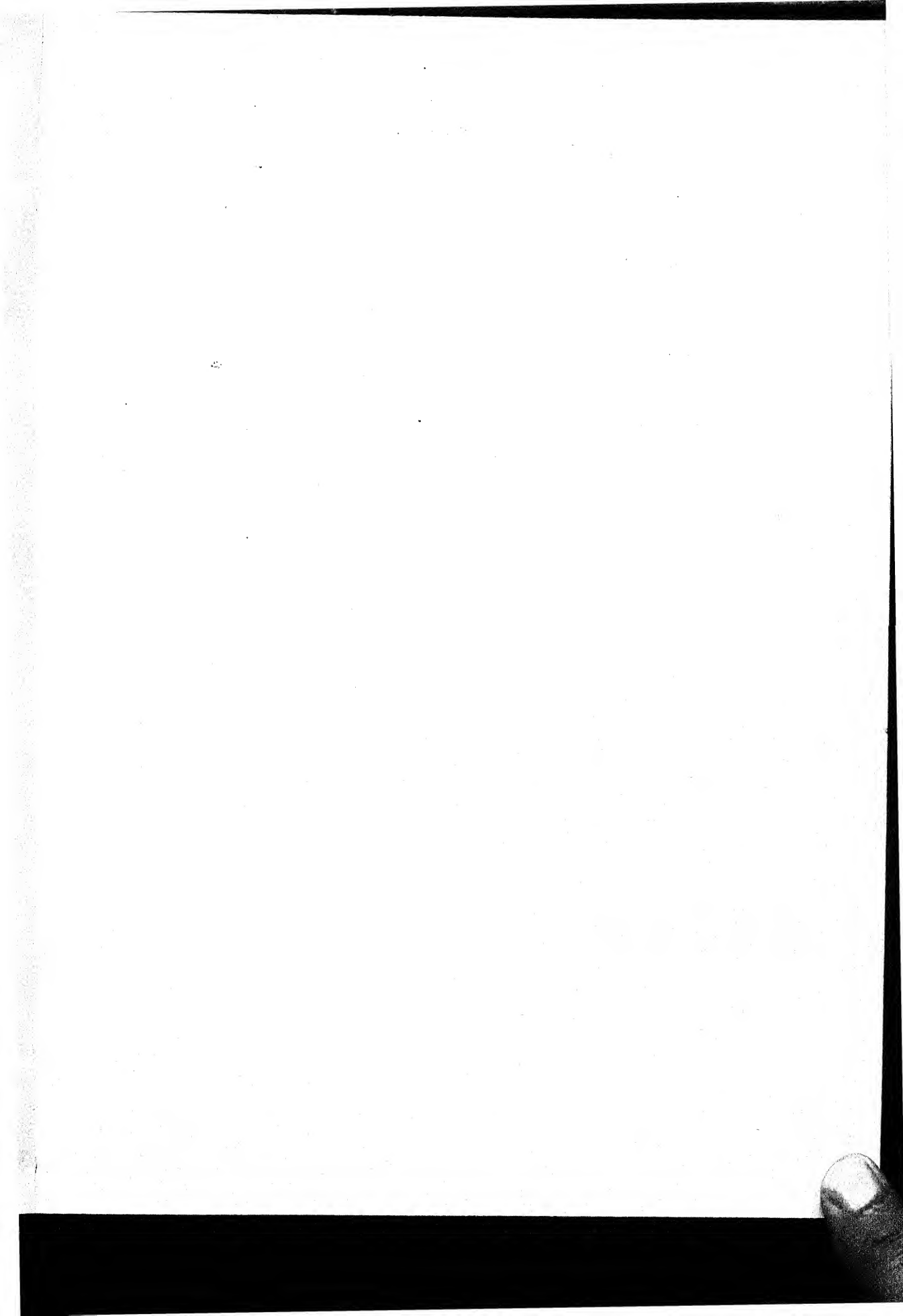
water, but nevertheless the presence of this small amount of argon argues the source of a certain proportion of the nitrogen as being the atmosphere.

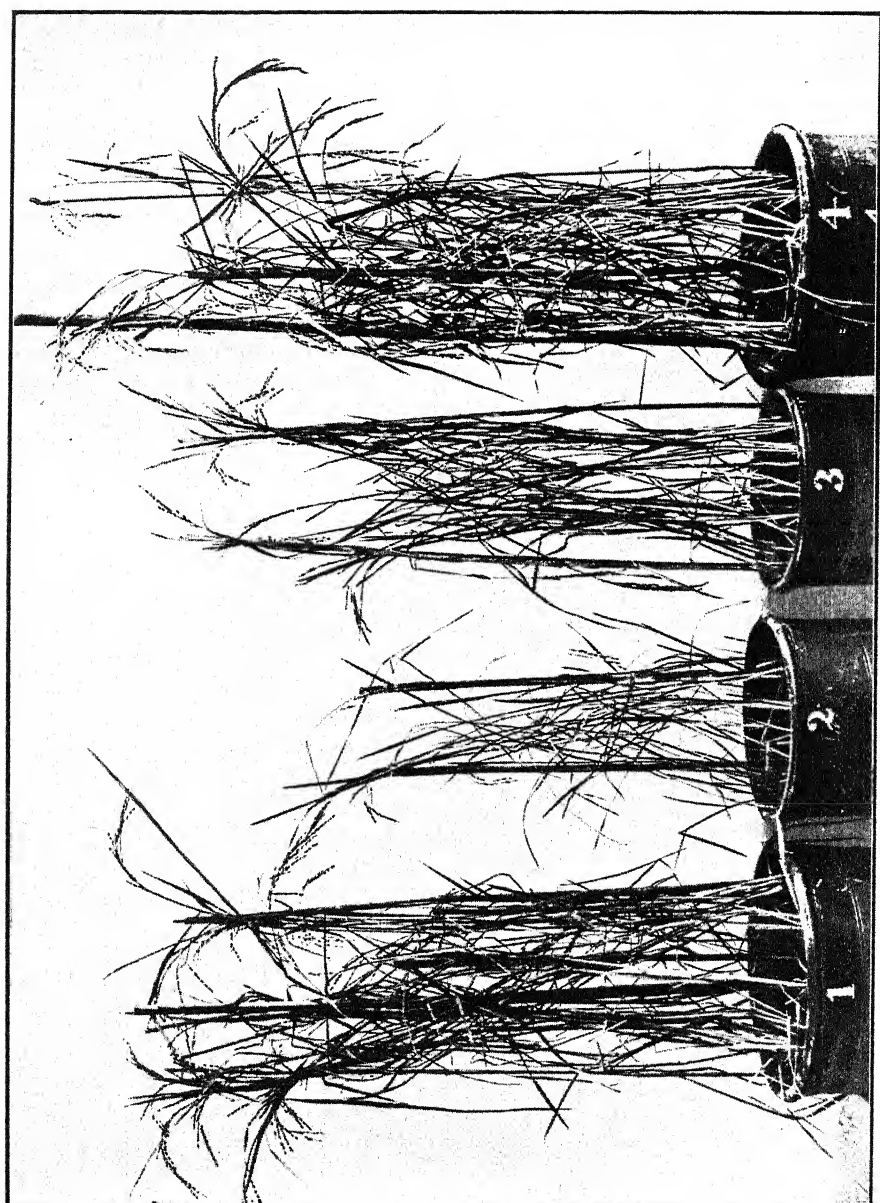
VI. The results obtained in these series of experiments clearly show that a considerable amount of the nitrogen contained in green manure is liberated in the gaseous form and so made useless so far as the feeding of the crop is concerned. At the same time, the fact that a crop of inferior value can be raised in sand culture through the agency of these manures shows that they have a certain direct value, but, even after making full allowance for this, it is evident that this value is very low and consequently the undoubted benefit derived from using these manures in certain types of soil must be ascribed mainly to their indirect manurial properties.

Definite evidence regarding the direct manurial value of green manures is not easy to obtain owing to the difficulty experienced in rendering their indirect action inoperative, without, at the same time, affecting relative cropping values. Thus copper sulphate has been used in these experiments to inhibit the action of the surface film and, the effect has been to inhibit the indirect effect of green manures in promoting root aeration. Nevertheless, a comparison between the cropping of pots treated with copper sulphate and similar untreated ones is rendered valueless by the fact that copper acts as a plant stimulant. In fact treated pots generally yield better crops than untreated pots. When, however, the formation of oxygen by the surface film is inhibited by preventing the access of light to it, it is found that crops from manured pots under normal conditions were on the average about 37 per cent. better than the darkened pots. The experimental results on which this comparison is based are given in the following table:—

TABLE VII.

Particulars of experiment	Wt. of grain in grams	Wt. of straw and chaff in grams	Total yield
Normal plant No. 1	7.95	22.75	30.70
" No. 2	6.13	19.00	25.13
" No. 3	9.55	17.47	27.02
Average of normal plants ..	7.87	19.74	27.61
Darkened pot No. 1	4.12	13.17	17.29
" No. 2	7.55	13.00	20.55
" No. 3	5.60	12.30	17.90
Average of darkened pots ...	5.75	12.82	18.58





In this experiment the method of darkening the surface was to cover the pot with a tin lid through which a hole was pierced to allow for the passage of the plant, and this hole was plugged with cotton wool so as to exclude any light. Care was also taken to conduct any tillers produced through the hole so that the green part of the plant was exposed to the light and only the organized film on the soil kept in the dark. The experiment was only a preliminary one and crude in type, but if this difference in cropping is ascribed to differences in root aeration then the indirect value of green manures must be considerably greater than the direct one. Further experiments of a similar type are being carried out.

A certain amount of indirect evidence with regard to this point is, however, available from a comparison of the crops raised under varying conditions of our experiments. The Plate opposite gives a photograph of the crops referred to :—

Pot I is the crop raised with sand and ammonium sulphate, Pot II with sand and green manure, Pot III with a mixture of sand and soil and green manure, and Pot IV with paddy soil and green manure. In all cases the seedlings were from the same seeds and raised at the same time, and all the pots were treated with copper sulphate solution, so that the indirect action of the green manure in increasing the root aeration is eliminated and the stimulative effect of the copper may be assumed to apply proportionately to all the crops. The pots, however, are not the same size and consequently the actual cropping values are not comparable, but the amount of green manure and the number of seedlings in each pot is proportional to the weight of the contents (except No. I which contains no green manure) so that a good idea of the relative cropping values can be obtained from the photo.

It is evident that the crop obtained with a mixture of sand and soil is much inferior to that obtained from soil alone, and again, that obtained with sand alone is in a similar way inferior to that from a mixture of sand and soil. The proportion of green manure to the contents of the pots and also to the number of seedlings present is the same, and it contains enough nitrogen to satisfy the needs of the crop, but, notwithstanding this, there is a diminishing output. The only factor which diminishes in value in a similar way is the proportion of paddy soil, and, consequently, it must be concluded that the direct manurial value of green manures is small and that the paddy crop is mainly dependent upon the soil nitrogen for its support.

If in addition it is borne in mind that easily decomposable soil organic matter undergoes rapid fermentation in these soils with the liberation of some of its nitrogen, then it would appear probable that the paddy crop is mainly

dependent upon that portion of the soil nitrogen which is in a more or less mineralized condition. This conclusion is supported by the cropping of Pot No. 1, containing nitrogen in the form of ammonium sulphate only, which is almost as good as that of Pot No. 4 and very much better than Pots Nos. 2 and 3.

It may be argued against this conclusion that the addition of sand to the soil has altered the mechanical texture of the soil and that, as swamp paddy is habituated to exceedingly fine soils, this has unfavourably affected the cropping. This objection is negated by the fact that it is possible to raise a good crop in sand culture only.

Another objection which may be raised is that by reducing the proportion of soil the toxic effect of decomposing green manure is intensified with baneful effect on the crop. Against this is argued the fact that manured pots of soil, or of mixtures of sand and soil, yielded better results than the corresponding unmanured pots.

Considering carefully the whole of the facts which have been collected regarding the relationship of green manures to the soil and crop, the only feasible conclusion which can be drawn is that the nitrogen of these manures has little actual manurial value, that the crop is mainly dependent upon soil nitrogen for its support, and that green manures owe the efficiency mainly to their indirect action on the soil and by increasing root aeration.

VII. In view of the conclusions thus arrived at it becomes necessary to consider carefully the whole subject of green-manuring paddy soils in order to evolve possible methods of application, or even of cultivation, which would lead to improved cropping results being obtained.

Hitherto, when experiments have been formulated for the purpose of obtaining the relative value of green manures (this must apply to some extent also to bulky organic manures of the type of oil cakes) it has been customary to base them upon the nitrogen content, or in other words, upon their direct manurial value. Comparisons of this type when instituted between different organic manures may yield valuable results as the functions performed are the same, but, between mineral and organic manures no such comparisons can be made, because, so long as cultural conditions remain as at present, the former are mainly direct acting manures and the latter are now shown to be chiefly indirect in type. In fact these two types of manures can be said to be members of complementary classes so far as paddy cultivation is concerned.

Further, the facts that swamp conditions are maintained throughout the whole growing season, and that under these conditions the nitrogen contained in organic manures is liberated in the gaseous form and thus made useless so far as the crop is concerned, indicate the impossibility of utilizing to the fullest extent both the indirect and direct values of green manures without some material and drastic alteration in the present practice. Nevertheless, the green manuring of paddy as practised in South India has yielded exceedingly good results in past years and the use of these manures is rapidly extending, as is witnessed by the rapidly increasing demand for seed of suitable crops such as wild indigo, but occasionally the results have been disappointing, and even retrograde, so that indiscriminate general advice to use them cannot be given. This uncertainty of reaction must be ascribed to the fact that these manures owe their efficiency to their indirect action.

The general statement that green manures are very effective for paddy may, however, be accepted and consequently the problem of utilizing them to the best advantage would seem to follow two distinct lines of enquiry, namely, (1) the institution of cultural methods which would result in the nitrogen they contain being rendered useful, and (2) to accept, in a broad way, the present conditions as being unchangeable, thus utilizing only the indirect value and to aim at feeding the crop by means of suitable direct manures.

With regard to the first line of enquiry the main difficulty to be faced in attempting to make the nitrogen directly available for the crop is in regard to the ordinary methods of cultivation. During the whole of the growing season the soil is saturated with water and is under anaerobic conditions, so that the nitrogen contained in any decomposable organic matter which may be present is mainly liberated in the gaseous form and thereby rendered valueless. If, therefore, this nitrogen is to be utilized two alternatives are open, either to greatly modify, or eliminate, the methods of swamp cultivation, or to apply the manure at such a time and under such conditions that the nitrogen can become an integral component of the soil before the irrigation season commences.

The first alternative raises issues which are so involved and aims at such radical changes in the present accepted conditions that it can be eliminated from the scope of this enquiry as not being feasible in the immediate future.

The second method is more feasible in that it would not interfere seriously with the ordinary methods of paddy cultivation, but it is obvious that this cannot be attained by applying the manures when swamp conditions are prominent. In addition it is necessary that the application should be made

under conditions which will permit of the organic matter becoming more or less mineralised, otherwise, when the cultivation season arrives and swamp conditions are attained, the organic matter will decompose and the nitrogen be lost. The nitrogen, in fact, must have formed a constituent of the soil before its loss can be obviated. In other words in order to utilize the nitrogen of green manures the primary object to be aimed at should be to feed the soil rather than the crop.

It is difficult to indicate how this desideratum can be arrived at, particularly as the irrigation problem interferes considerably with any proposals to grow green crops out of season. Still, for instance, in double cropland, *i.e.*, land on which two consecutive crops are raised under irrigation followed by a dry off-season, it may be feasible to sacrifice the second crop on a portion of the land to grow a green manure crop. This crop could then be distributed over the whole at the end of the cropping season and worked in, so that decomposition would occur when the soil was drying, and therefore under more aerobic conditions, with the formation of stable soil nitrogen utilizable by the next paddy crop.

Many schemes of wide variation having this object in view could no doubt be formulated to attain this end, but, as a rule, they would be opposed to general cultural practices, and may even in themselves lead to harmful results. Generally speaking, this aspect of the case is not attractive, for it is concerned with unexplored ground, is totally opposed to the general cultural practice in South India, and would materially decrease the undoubted indirect value of these manures by leading to a destruction of carbonaceous material before the season of swamp cultivation commenced.

The second line of enquiry, which accepts the view that green manures only affect the crop in an indirect manner and do not supply food to the plant, seems to be the one which opens out the most promising field for immediate progress. From this point of view, the benefit which may accrue from applying green manures is determined by factors totally unconnected with the manure itself. A soil whose mechanical and biological characteristics, for instance, are not of a suitable type for the paddy crop, cannot benefit greatly from green manuring unless the manure itself ameliorates those conditions. In the same way the value of green manures will be approximately proportional to the intrinsic cropping value of the soil to which they are applied, for no great value can be attached to their effect on root aeration if the soil itself is incapable of raising a good crop.

These considerations account for the uncertain action of green manures when used alone and lead to the conclusion that their value goes

approximately hand-in-hand with the actual cropping value of the soil. This being the case their maximum efficiency can only be reached when other soil factors are simultaneously improved, and, of these factors, that of the manurial value of the soil is most easily affected. The most promising line of experiment would be to find a suitable system of manuring which would employ green manures in conjunction with mineral manures.

Generally speaking, paddy soils in South India are deficient in phosphates and nitrogen, and of these the former is easily made good by the use of bone-meal, superphosphate, etc. With regard to the latter the position is simple, for any improvement of the cropping, by the direct supply of nitrogen, must be brought about by the use of manures which will answer certain requirements. They must (a) contain no decomposable organic nitrogen compounds, (b) the nitrogen must be in a form assimilable by the crop, and (c) be retained by soil and not liable to be leached out. The first condition throws at once all the bulky organic manures out of court and leaves the choice open to the limited class of artificial nitrogenous mineral manures. Of these, nitrates are unsuited owing to the facts, that they are not retained by the soil and, that they readily undergo denitrification in paddy soils with the production of gaseous nitrogen and even poisonous nitrites. The only manures which answer completely all these requirements are ammonium compounds and compounds of the type of cyanamide which yield ammonia on decomposition. Both ammonia and cyanamide are excellent paddy manures and when suitably applied, yield good results. They, however, lack the indirect value of organic manures, and, in particular, they cannot increase the intensity of root aeration, so that, in order to obtain the best all round results it would appear desirable to use them in conjunction with green manures. This combination would, on the one hand, provide the requisite nitrogen for the growth of larger crops, and, on the other, produce the most favourable conditions for healthy root development. Some tentative experiments carried out recently by us support this contention.

Four pots were taken, all of the same size, and all containing the same weight of soil. One was left unmanured, the second was green manured only, the third was manured with ammonium sulphate and the fourth received both ammonium sulphate and green manure, in amount equal to that given in the second and third pots. These pots were puddled and had the same number of seedlings transplanted into them. Another series of pots were laid down containing a mixture of four parts of sand with one part of soil and to which

was added basic super and potassium sulphate. The results obtained are as follows :—

TABLE VIII.

Soil used	Manure present	Total crop in grams	Wt. of grain	Wt. of straw and chaff
Soil only ...	No manure ...	54.6	17.8	36.8
	Green manure ...	65.6	18.8	46.8
	Am_2SO_4 ...	180.1	60.6	119.5
	Green manure and Am_2SO_4 ...	214.0	75.0	139.0
Sand and soil	No manure ...	15.6	5.0	10.6
	Green manure ...	35.1	11.6	23.5
	Am_2SO_4 ...	114.0	41.6	72.4
	Green manure and Am_2SO_4 ...	113.0	37.3	75.7

In the case of the pots containing only paddy soil, where the conditions are favourable for the utilization of the green manure for root aeration, it is apparent that the effect of the green manure is approximately proportional to the crop raised in the corresponding pots without green manure. Thus although the effect of adding ammonium sulphate has been to increase the total cropping value about 230 per cent. yet the increase due to the addition of green manure has been constant *viz.*, about 20 per cent., with soil alone and 19 per cent, when ammonium sulphate is present.

With regard to the pots containing a mixture of sand and soil, there is no trapping of the soil gases under the influence of the roots of the crop, and, consequently, the indirect value of the green manure has been greatly reduced. This is borne out by a comparison of the crops obtained from the pots containing Am_2SO_4 .

The general position arrived at, therefore, is that a suitable combination of direct manures and green manures will produce the largest outturn from suitable land, thus opening out a large field for experiment. The position is, however, complicated by the uncertainty of the result to be expected from the use of green manures, and this entails a detailed and close study of the factors concerned, before definite rules can be formulated. It is quite possible, in fact, that, in extreme cases, it will be found that the use of direct manures only may yield the best results.

VIII. Finally attention must be drawn to the probable relative value of the two systems of green-manuring commonly practised in South India *i.e.*, to a comparison of the system of growing a green crop on the soil to which it is to

be applied with that of manuring with green leaf or a green crop brought from an external source.

The green crop usually grown in paddy soils is leguminous in character and obtains a proportion of its nitrogen from the atmosphere; but this proportion is undetermined and, at least in the richer type of these heavy soils which are fairly well supplied with nitrogen, it would appear probable that the major portion is derived directly from the soil. In the case of non-leguminous crops the whole of the nitrogen would be taken from the soil. When the green crop is puddled into the soil decomposition occurs and most of the nitrogen contained in it is dissipated as nitrogen gas and becomes valueless from the manurial point of view. Consequently the practice of growing green crops in the paddy soil to which they are to be applied tends to deplete the store of soil nitrogen and to lead to reduced cropping so that the practice of bringing in the green manure from external sources would appear to be preferable.

This conclusion appears to be warranted by the facts now available, but it is possibly of too general a character and probably would only apply to the richer types of soil. It remains however an important aspect of the problem of paddy manuring and one which is worthy of close study.

COIMBATORE, }
January, 1916. }

PREFACE.

As stated in the body of this report, the work on which it is based was commenced in 1907, in collaboration with Messrs. Cross and Bevan of London. "Heart damage" is, however, linked up with the question of watering of jute and was therefore one of the reasons for the outcry, from 1901 onwards, regarding the alleged deterioration of jute. The latter was the immediate cause of the writer's appointment, in 1904, to make a special study of fibres.

The attention given to the investigation into "heart damage" has necessarily been intermittent, owing to the pressure of more urgent demands on my time; but it was also advisable that no hasty conclusions should be drawn in dealing with a subject which is often the cause of commercial disputes.

I have to express my indebtedness to the Hon'ble Sir A. Birkmyre (Messrs. Birkmyre Bros.), Mr. Brackenridge (Messrs. J. C. Duffus & Co.), Mr. D. L. Millar (Messrs. D. L. Millar & Co.), and Mr. P. E. Suttie (Messrs. Sinclair Murray & Co.) for kindly advice and for reading through the manuscript.

I am also indebted to Dr. Butler, Imperial Mycologist, Pusa, for identifying the mould *Aspergillus fumigatus*, Fres., and for his note on the same, which is published herewith as an appendix.

My best thanks are due to Mr. George Macdonald of Bara, Champaran, Bihar, for the use of his press in the *kutchu* (3½ maunds or 280 lb.) baling test. I also wish to acknowledge with many thanks the help given by Mr. H. M. Shircore (Messrs. Sarkies & Co. of Narayanganj), not only in lending the firm's press for all three *pucca* (5 maunds or 400 lb.) baling tests, but also in the considerable personal trouble to which he went in order to ensure the success of the tests.

My Assistant, Mr. N. C. Basu, M.Sc., has done valuable work in the more recent stages of the investigation.

R. S. F.

Dacca :
3rd July, 1917,



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"HEART-DAMAGE" IN BALED JUTE.

BY

R. S. FINLOW, B. Sc., F.I.C., F.C.S.,
Fibre Expert to the Government of Bengal.

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PART I. INTRODUCTORY.

THE more recent work on "heart damage" arose out of correspondence, 1905, between Messrs. Cross and Bevan of London, and the author of this paper regarding the natural moisture content of jute.

Previous references to the subject seem to be confined to the publications of Messrs. Cross and Bevan. In 1880, in a paper on the chemistry of bast fibres, read before the Owen's College (now Manchester University) Chemical Society, these authors, in dealing with the action of dilute acids on jute, describe "an interesting species of fermentation, which takes place when masses of jute are allowed to lie in a damp state, in consequence of which the fibre undergoes a similar dissolution to that which is induced by hot acids.....". The sample examined "contained as much as 10 per cent. of matter soluble in water....." and, "with a 1 per cent. solution of caustic soda, as much as 23 per cent. of the weight of the fibre was removed in solution.....". "The decomposition which had taken place resembled, therefore, that which is effected by hot dilute acids in every particular with the exception that, in the latter case, traces only of the aromatic constituents are rendered soluble."

Messrs. Cross and Bevan, in 1882 (*Journal of the Chemical Society*, XLI, 1882, page 92), describe the examination of a sample of damaged jute which yielded an aqueous extract which was brown, "astringent to the taste, and, at the same time, strongly acid to test paper."

Subsequently no further progress seems to have been made until 1907 when, in collaboration with Messrs. Cross and Bevan, the writer commenced a practical investigation into the conditions necessary for the production of

"heart damage" in baled jute. The series of experiments was concluded in due course, and in May, 1908, a report¹ was presented to His Majesty's Secretary of State for India by Messrs. Cross and Bevan. Since then the writer has carried the investigation further, and the present communication is the outcome of the latter work.

CHARACTERISTICS OF "HEART DAMAGE."

The deterioration in jute known as "heart damage" is so called, because its effects appear first in the centre of the bale of fibre in which it takes place. It is a phenomenon which has long been familiar to members of the jute trade, by whom its incidence is universally ascribed to the presence of an undue proportion of water in the fibre. "Heart damage" is usually associated with baled jute; but it is important to remember that the storage of a sufficient bulk of unbaled jute in a damp condition will produce an exactly similar form of deterioration. For instance, at country markets or collecting centres, in wet weather, it is common to see loose jute beginning to heat. Such jute is always damp, and a rise in the temperature of the mass is recognized as a warning that the jute must be dried at once if a marked weakening, or even more serious damage to the fibre, is not to ensue. "Heart damage" is, however, the term usually applied in reference to deterioration of baled jute, and especially to the deterioration of *pucca*,* *i.e.*, the large 5-maund, bales, in which form the whole of the jute which goes to foreign markets is exported. It is said that 3 per cent. of the total imports of jute into Dundee in 1906 were rejected on this account.

It will be shown later that "heart damage" is never met with in good dry fibre, and that it only takes place in the presence of excessive moisture, *i.e.*, a moisture content to which it would be practically impossible for a sample of fibre to attain by absorption from the atmosphere under the most favourable conceivable conditions. Further, the percentage of moisture which suffices for the production of damage seems to vary inversely as the tightness with which the fibre is packed. Thus a small loose heap of jute would probably require nearly 50 per cent. of water for damage to take place. In a larger heap the necessary moisture content would be proportionately less in the region of greater pressure, and in a *pucca* bale only about 25 per cent. seems to be required. In a *kutch*a bale, in which the pressure is less than

¹ Report by Messrs. Cross and Bevan on investigations of jute fibre in relation to "heart damage" of baled jute, India Office, 1908.

* A *kutch*a (Hindi, imperfect) bale commonly weighs 3½ maunds or 280 lb., and is less tightly pressed than the *pucca* (thorough) bale which weighs 5 maunds or 400 lb. There are, however, other *kutch*a bales, weighing from one maund to three maunds each.

in a *pucca* bale, decidedly more than 25 per cent. of water seems to be necessary in order that damage may take place.

A reasonable explanation of this seems to be that the damage takes some time to develop, and that the loss, by evaporation, of the water required for its progress, is proportionately prevented by tight packing, which would also tend to produce a more even and permanent distribution of the water throughout the mass. It was at first thought that the greater exclusion of air, also due to tight packing, might facilitate the development of the damage; but a biological investigation into the latter, now in progress, does not support this view; on the other hand, there are indications that the purely physical effect, on the fibre, of the great pressure employed in a *pucca* (400 lb.) bale may help the incidence of the damage.

In a single *pucca* (400 lb.) bale of sufficiently damp jute, the temperature begins to rise after a period varying from about 10 days to six weeks (according to the temperature of the air at the time of, and subsequent to, baling), and continues to do so gradually, if there is sufficient moisture, until the thermometer reaches about 40° C. (104° F.), where it may remain practically constant over a period of many weeks. During this period the damage is taking place, and a fall in the temperature indicates that the action is slackening, or has ceased, whether on account of completion or because of insufficient moisture.

The appearance of the interior of a bale which has suffered damage differs considerably according to the amount of water absorbed by the fibre before baling. If the water percentage is below a certain point, the temperature will not rise; but the contents of the bale, on opening, will have a musty smell and the fibre will be weakened, more or less in the proportion in which the water percentage is sufficient for complete damage: typical "heart damage" does not occur under these conditions. When the moisture percentage exceeds the point mentioned above, a definite and pronounced rise of temperature, accompanied by typical "heart damage", ensues, and the fibre completely loses its tensile strength. When the percentage of water is not too high, very little discoloration accompanies the damage, and in these circumstances the interior of the bale often has a quite strong winy smell, which is an indication to what great length the decomposition has proceeded. With a still higher moisture percentage the fibre becomes decidedly wet, and the damage finally approximates to putrefaction, which is accompanied by great discoloration.

Very often it is possible to detect evidence of organic growth on the damaged fibre: for instance, a white beady growth seems characteristic; but

this is often, especially in excessively watered bales, masked by the black spores of a mould—*Aspergillus fumigatus*, Fres. The latter is probably not one of the necessary agents causing the damage, but rather seems to develop on the products of decomposition (*vide* Appendix I).

There can be no doubt at all that "heart damage" is the result of biological action, and an investigation into its cause has already resulted in the production, in the laboratory, with bacterial cultures taken from a damaged bale, of all the characteristic phenomena of "heart damage." It is intended to make this latter investigation the subject of a later communication.

We have seen that "heart damage" involves a radical physical change in jute; for instead of remaining a fibre of considerable tensile strength it becomes a spongy, brittle mass which can easily be rubbed into a fibrous powder. "Heart damaged" jute is, therefore, entirely useless for spinning purposes.

The chemical changes produced are equally great, the most important being—

- (1) Great diminution of cellulose content.
- (2) A far larger proportion of the weight of the fibre becomes soluble in water and in simple chemical reagents.
- (3) Diminution in the yield of furfural on boiling the fibre with hydrochloric acid.

The microscopic appearance of a damaged sample of jute is not so striking as the profound chemical changes might lead one to believe. Fragments of damaged fibre indeed show very little sign of any great change, beyond the fact that the bundles of ultimate filaments, whose aggregation forms the fibre, are seen to be broken across at right angles to their longitudinal axes. This is, of course, only another way of describing the complete loss of tensile strength already referred to. Even on boiling with alkali, damaged fibre shows comparatively little sign of change, although the chemical analysis may show that one-third of its cellulose has been dissolved away. Such a result could only have been achieved in sound fibre by prolonged acid hydrolysis. Under the microscope the ultimate fibres in the damaged bundles are apparently transversely marked in a large number of places; on the other hand, a sample of sound jute, brought to a similar phase by chemical treatment, does not exhibit these markings, which would appear to be fractures.

It is worth recording, as bearing on the apparently easier incidence of "heart damage" in baled jute (*vide* p. 35), that fibre which has been baled frequently shows, on examination under the microscope, transverse markings,

which are much more rarely visible in fibre which has not been baled. It is a well-known fact that an experienced person can tell, by mere cursory examination, whether a sample of fibre has been baled or not. This distinction is possible owing to the "kinks" caused by the great pressure in baled fibre, and it is reasonable to suppose that, in this case, the transverse markings are only the microscopic aspect of the effect of pressure.

PART II. BALING TESTS.

1. TESTS WITH KUTCHA BALES.

Four sets of baling tests have been carried out, the first of them being done, as already explained, in collaboration with Messrs. Cross and Bevan. Mr. George Macdonald of Bara, Champaran, Bihar, to whom we are much indebted, lent his press for this test, in which only *kutchha* ($3\frac{1}{2}$ maunds or about 280 lb.) bales were used. Six of the bales were made up from a large, uniform bulk of fibre, with sufficient added water to bring the percentage of moisture up to approximately 30 per cent. Sugar, as typifying easily fermentable matter, as well as certain other chemicals, was also added to some of the bales, which were shipped to London in the ordinary way. On being opened in London several months later, it was discovered that, although some of the fibre was weakened, no serious damage had taken place in any of the bales, the contents of which were ultimately sold as first class fibre. No conclusion could, therefore, be drawn regarding the amount of moisture which is necessary for the incidence of "heart damage," excepting that it is over 25 per cent., and probably over 30 per cent. for bales of the size and tightness of packing in question; however, the following inferences, among others, seemed justifiable, always remembering that they apply only to the particular size and type of bale used (*vide report loc. cit.*).

1. "This excessive moisture" (approximately 25 per cent.), *per se*, causes no evident damage nor lowering of the quality of the fibre.

2. "The presence of easily fermentable matter, associated with excessive moisture, does not constitute a combination necessarily dangerous to the fibre."

3. Some "mould and bacteria growths may develop on the fibre without causing deep-seated changes of the fibre substance."

4. "The specific chemical features of 'heart damage' are profound changes in the fibre substance, as a complex, without correspondingly large changes in the constitution of the approximate constituent groups."

5. It is considered that the hydrolytic changes taking place in the cellulose constituent of the fibre, resulting in the formation of "nutrient or assimilable matter available for living organisms, are an important object of research in

agricultural chemistry.....and of positive economic value to other industries."

2. TESTS WITH PUCCA BALES.

The baling in the remaining tests was done by Messrs. Sarkies & Co., of Narayanganj, and we are much indebted to them for the use of their *pucca* press on these occasions.

The fibre for all bales in each test came from the same bulk ; so that each bale in any test was comparable, as far as possible, with any other.

For the purpose of adding the water, the fibre was spread out on the wooden floor of the press room, and the required amount of water was added in a fine spray. The fibre was turned over once during the spraying, to insure even application of the moisture, and baling was done immediately after the addition of water, so as to prevent loss by evaporation. As it was necessary to register any subsequent rise of temperature which might take place in the bale the following arrangement was made: pieces of strong iron tube, 2 inches in diameter, and approximately 1 foot long, were corked at one end, and then packed as tightly as possible with sand, after which the other end was corked. As each bale was being made up one of these tubes was introduced ; so that one end of the tube reached about to the centre, while the other end of the tube was flush with the outside of the bale. The sand helped to prevent the tube from being flattened out when the pressure of two tons to the square inch was applied to the bale, and sufficient of it was afterwards scraped out to allow a maximum thermometer to be completely immersed in the tube, the outer end of which was then closed with a tight wad of cotton-wool. In this way it was possible to register, with some accuracy, the maximum temperature attained by the centre of the bale.

Method of estimating moisture.

A weighed portion of moist fibre is placed in an oven at 105° C. (221° F.), and dried until it ceases to lose weight. The loss of weight, multiplied by 100 and divided by the original weight of damp fibre, gives the percentage of moisture in the sample : thus :—

Weight of damp fibre	..	..	10 gm.
Loss of weight	..	..	1 „
Then true percentage of moisture	$\frac{100 \times 1}{10}$	..	10 per cent.

It is important to contrast this method with that which usually obtains in trade circles. The latter is described by Mr. Suttie as follows :—"Dry

the jute, over bamboos, for several hours, in the sun; store overnight in a godown* and weigh in the morning. The difference between the weight taken before drying, and the weight the following morning would indicate the real percentage of artificial moisture, the assumption being that any of the natural moisture taken from the jute is recovered from the atmosphere overnight." It is obvious that this treatment cannot drive off all the moisture from the fibre, which always retains a certain proportion, varying from about 5 per cent. to 15 per cent., according to the thoroughness of the treatment. The laboratory method, which is similar to that used in conditioning houses in Europe, secures complete desiccation of the fibre, and the results obtained by it are correct, and always higher, by from about 5 per cent. to 15 per cent., than those given by the trade method. To convert the laboratory moisture percentage into those obtained by the trade method, it would, therefore, be necessary to subtract from 5 per cent. to 15 per cent. Thus if the moisture content, as determined in the laboratory, is 20 per cent., the trade figures would be between 5 per cent. and 15 per cent.

First Series of Pucca Baling Tests.

The main object of this series of tests with *pucca* bales was to make sure of producing "heart damage"; and 25 per cent. of water, making 35 per cent. with the original 10 per cent. contained by the fibre, as representing a quantity certain to secure this object, was therefore added to one bale. The contents of a second bale were made up to about 29 per cent., as it seemed probable that this moisture content would be just below, or just on, the lower limit at which damage takes place. A further object was to show that good dry jute does not suffer "heart damage", and for this purpose a bale was made up without the addition of water, *i.e.*, containing 10 per cent. of moisture.

The quality of fibre used in all the bales was "Threes", guaranteed to contain 75 per cent. sacking warp and the respective quantities of fibre and added water were calculated as follows:—

Absolute weight of water in a bale.. $\frac{\text{Weight of moist fibre} \times \text{percentage of water}}{100}$

If the original fibre contains 10 per cent. moisture and it is required to make the percentage up to 29 per cent:—

By the above formula, moisture percentage	..	29 per cent.
Total weight of moist fibre in bale	..	.. 400 lb.

* Warehouse.

Therefore total weight of water in a bale $\frac{400 \times 29}{100}$, i.e., 116 lb.

Therefore absolutely dry fibre 284 ,,

but the original fibre contains 10 per cent. of moisture,

i.e., $\frac{284}{10}$, i.e. 31.6 ,,

Therefore weight of water to be added to bring
moisture percentage up to 29 per cent. is 116 minus

31.6, i.e. 84.4 ,,

and the weight of fibre containing 10 per cent. of water

to be taken would therefore be 315.6 ,,

Similarly for 35 per cent. of moisture the weight of

water to be added is $\frac{400 \times 35}{100}$ minus $\frac{260}{9}$.. 111 ,,

and the weight of fibre containing 10 per cent. of water

would therefore be 289 ,,

The final contents of the bales were as detailed in the following table :—

Bale No.	Original fibre containing 10 per cent. moisture	Absolutely dry fibre	Water	Weight of water added to original fibre	Total weight of water in bale	Final per- centage of water in bale
1	lb. 400	lb. 360	lb. 40.0	lb. ...	lb. 40	Per cent. 10
2 ...	316	284	31.6	84.4	116	29
3 ...	289	260	29.0	111.0	140	35
4 ...	289	260	29.0	111.0	140	35

These bales were made up on May 21st, 1912, and they were opened on September 15th, 1912, i.e., after an interval of 116 days. The following notes were made at the time of opening the bales :—

Bale No. 1. Unwatered jute.

This bale was absolutely normal and showed no signs of any damage. Its weight had increased by 3 lb., which is accounted for by its prolonged exposure to the damp atmosphere of the monsoon. The maximum thermometer in the interior of the bale, which was at 86° F. at the time of baling, showed that no rise of temperature had taken place.

Bale No. 2. Jute to which 19 per cent. of water had been added, i.e., containing 29 per cent. moisture.

This bale had lost 20 lb. in weight, and the thermometer, which registered 86° F. at the time of baling, showed a maximum of 98° F. or a rise of 12° F.

The bale had not burst : but the rise in temperature indicated a considerable amount of fermentation. The contents of the bale, which were still warm on opening, were uneven : over one half of the fibre was perfectly strong, but the remainder was all more or less damaged, some of it badly so. Although the damage seemed to be rather unevenly distributed, the chief deterioration was in the centre. There were no signs of the black mould spores so characteristic of bales Nos. 3 and 4.

Bale No. 3. Containing 35 per cent. of water.

This bale had burst and the fibre was so damaged that the bale could not be weighed. The thermometer showed a maximum temperature of 101° F. or a rise of 14° F. The contents of the bale had a musty smell and were badly damaged. When rubbed with a hard body a black line was left on the fibre, this probably being due to bursting of black mould spores. The temperature was not nearly high enough to produce carbonization of the fibre.

N.B. It has since been established that the blackening is due to mould spores ; but the mould appears only to feed on the decomposition products of the damage and does not seem to be an agent producing it (*vide* Appendix I).

Bale No. 4. Containing 35 per cent. of water.

This bale had also burst, the maximum temperature was also 101° F., and the contents of the bale were similar in all respects to those of No. 3, being completely damaged.

General Remarks.

These experiments were only preliminary ones in the attempt to determine the limit of moisture content of the fibre beyond which "heart damage" is likely to occur. It is plain that 35 per cent. is a long way beyond this limit.

The result in the case of bale No. 2 is less certain ; but it appeared that the point at which definite damage can take place is probably rather below 29 per cent. of water. On the other hand, it is very obvious that good dry fibre does not suffer damage when baled, which supports the universal opinion of the members of the jute trade.

The rise of temperature in the damaged bales is very typical of biological action.

Second Series of Pucca Baling Tests.

In this series it was decided to use 29 per cent. water as a maximum, and also that the moisture content of other bales should diminish by increments of about 2 per cent. It was expected that the bales containing most water would suffer, and that those containing least would not; but it was hoped one of the bales might be just damaged, while the one containing the next lower water percentage would not show marked signs of deterioration.

It was hoped also, in this series, to throw light on a point raised by a member of the jute trade, *viz.*, whether a bale originally containing dry jute would, after wetting of the exterior of the bale, as by complete immersion for a short time, suffer "heart damage," even if the fibre in the centre of the bale is not wetted during the period of immersion. A further object was, if possible, to throw some light on the production of "ship damage", which is fully discussed on pp. 57—59. For this purpose a bale containing 4 maunds 38 seers of dry jute was immersed in water for 45 seconds, after which it weighed 5 maunds 23 seers, having taken up 25 seers, or roughly about 50 lb. of water. The total moisture content of the fibre was then roughly 25 per cent.

The whole of the jute used was one sample, *viz.*, "Threes" containing 70 per cent. warp; but occasional hanks of *bogi* (fibre of *C. olitorius*) were to be found. The original moisture content was 16 per cent.

Bale No.	Original fibre containing 16 per cent. moisture	CONSISTING OF		Weight of water added to original fibre	Total weight of water in bale	Final percentage of water in bale
		Absolutely dry fibre	Water			
1 ...	lb. 401	lb. 336	lb. 64	lb. ...	lb. 64	Per cent. 16.0
2 ...	365	307	58	35	93	23.0
3 ...	354	297	57	46	103	26.0
4 ...	336	282	54	64	118	29.5
5 ...	346	291	55	54	109	27.0
6 ...	406	341	65	50	115	25.0

The bales were made up on the 9th February, 1913, and they were opened on the 29th March, 1913; *i.e.*, only about 6 weeks later. The following observations were made at the time of opening.

Bale No. 1. No added water, 16 per cent. natural moisture.

Interior of bale quite cool, fibre fairly dry to the feel and certainly undamaged; water content of fibre at the time of opening the bale 16 per cent.

Bale No. 2. Total water content 23 per cent.

Fibre damp with a musty smell, and rather weaker than that of No. 1; but not sufficiently so to affect its market value. The interior of the bale was cool. Water content of fibre at the time of opening the bale 20·83 per cent.

Bale No. 3. Total water content 25·6 per cent.

Fibre damper and had a decidedly stronger smell than that of No. 2; the small amount of *bogi* did not feel so damp. The contents of the bale had not deteriorated sufficiently to affect the value of the fibre, and the interior of the bale was cool. Water content of fibre at the time of opening the bale 23·1 per cent.

Bale No. 4. Total water content 29·5 per cent.

The interior of the bale was hot, *i.e.*, 95° F. (35° C.), the temperature having risen from 86° F. (29·5° C.). The fibre had a strong musty smell and was badly "heart damaged" in the centre. Water content of fibre at the time of opening the bale 24·8 per cent.

Bale No. 5. Total water content 27 per cent.

Bale quite cool in interior; fibre had a strong musty smell and damp feel; but though decidedly weakened there were no marked signs of damage, and the value of the fibre was not seriously affected. A small amount of *bogi* in the bale was not weakened so much as the fibre of *C. capsularis*. Water content of fibre at the time of opening the bale was 23·8 per cent.

Bale No. 6. Dry fibre immersed in water for 45 seconds after baling.

This bale was quite cool in the centre, but the outside fibre at a depth of about 3 inches was decidedly damaged to such an extent as to affect its value seriously.

General Remarks.

This test confirmed the former one in placing the point at which "heart damage" takes place below 30 per cent., but, as the next series will show, the deterioration can take place with a distinctly lower percentage of moisture than 30 per cent., provided sufficient time and a suitably high initial temperature be given. It seems possible in fact that bale No. 5 certainly, and probably, to a less extent, bale No. 3 also would have suffered serious damage, if a longer period than 6 weeks had been allowed. In this case it has to be noted that the baling was done at the coldest period of the

year, and that the temperatures to which the bales were exposed during the whole of the first month were very low, as the following readings, kindly taken by Mr. Shircore, show:—

Temperature of bales in degrees Fahrenheit.

Date of baling	No. 1	No. 2	No. 3	No. 4	No. 5
11th February, 1913 ...	80°	79°	82°	80°	84°
19th February, 1913 (one week after baling) ...	71°	76°	76°	76°	76°
25th February, 1913 ...	78°	76°	80°	80°	80°
3rd March, 1913 ...	72°	70°	74°	74°	74°

It has been ascertained, in the course of the bacteriological investigation already referred to, that the optimum temperature for the growth of the organisms causing "heart damage" probably lies somewhere between 100° F. (38° C.) and 105° F. (41° C.), and that any marked diminution of temperature depresses their activity to an extraordinary extent. In view of this knowledge, which we did not at that time possess, it is not surprising that, at the low temperatures recorded above, no very serious change took place in the majority of the bales.

It has already been noted that the fibre used in these tests contained a very small amount of the fibre of *C. olitorius*, known variously to the trade as *bogi*, *tosha*, *deopat*, or *desi* jute, and there were indications that the latter is not so liable to suffer damage as the fibre of *C. capsularis*. No definite conclusions can be drawn from such fragmentary evidence; but the point seems worth following up. It is also highly probable that different qualities of the same kind of fibre would vary considerably in their susceptibility to damage under given conditions of moisture; for instance, a slightly over-retted fibre would probably be more likely to undergo "heart damage" than a good sound sample. Similarly it might be anticipated that a soft fluffy fibre would be less resistant than hard jute. These, however, are only speculations, and further work is obviously needed to obtain more definite information.

Third Series of Pucca Baling Tests.

The last series had indicated that 29 per cent. of moisture was sufficient to produce "heart damage" in less than seven weeks when the temperature during the first month was exceptionally low. It was therefore fairly certain that, given a longer time, decidedly smaller quantities of water would prove sufficient for the development of the deterioration. For this reason it was decided to commence with 27 per cent. as the moisture content of the dampest

bale in the series, and the remaining four bales contained respectively 26 per cent., 25 per cent., 24 per cent., and 23 per cent. of water.

The following table gives detailed information regarding weights of jute, quantities of water added, etc. :—

Bale No.	Original fibre containing 10·4 per cent. moisture used	CONSISTING OF		Weight of water added to original fibre	Total weight of water in bale	Final percentage of water in bale
		Absolutely dry fibre	Water			
	lb.	lb.	lb.	lb.	lb.	Per cent.
1 ...	314·0	308	35·80	56·2	92	23
2 ...	339·3	304	35·30	60·7	96	24
3 ...	334·8	300	34·80	65·2	100	25
4 ...	330·4	296	34·36	69·6	104	26
5 ...	325·9	292	34·00	74·0	108	27

The bales were made up on the 12th March, and they were opened on the 23rd June, 1915. It should be mentioned that, owing to the pressure during baling, a small quantity of water was squeezed out from bales containing 25 per cent. of water and over ; the amount thus lost was too small to be of any consequence ; but it indicates that, in a *pucca* bale containing 25 per cent. moisture, all air space is completely filled with water.

The following table shows the respective temperatures of the bales on three separate dates after baling :—

Temperatures of the bales in degrees Fahrenheit.

Date	No. 1	No. 2	No. 3	No. 4	No. 5
17th March, 1915 (6 days after baling) ...	86°	82°	86°	86°	86°
3rd May, 1915 (6½ weeks after baling) ...	84°	86°	104°	88°	102°
26th June, 1915 (14 weeks after baling and at the time of opening) ...	86°	87°	104°	104°	104°

The following notes were made on the spot at the time of opening the bales :—

Bale No. 1. Total moisture content 23 per cent.

Fibre, moist to the feel, has lost the typical smell of jute and had a musty odour, though not a strong one. There were isolated patches of black spotted fibre, looking like agglomerations of spores ; in these places the fibre is distinctly weak, but elsewhere there is no serious diminution of strength.

Bale No. 2. Total moisture content 24 per cent.

Fibre decidedly weaker than No. 1, even in places where there is no visible growth; but the failure of the temperature to rise shows that no actual "heart damage" has taken place. There was comparatively little of the black mould growth, although the fibre is weak; and it has still to be proved that the mould is one of the causes of the damage. The fibre has a decidedly stronger musty smell than that of bale No. 1.

Bale No. 3. Total moisture content 25 per cent.

The fibre in the centre of this bale is completely damaged, being absolutely weak, as would be expected from the marked rise in temperature which has taken place in the bale. The temperature is moreover still at its maximum, showing that, even after 14 weeks, the fermentation causing the damage is still actively proceeding. The black mould was present everywhere, but not in large quantity, and a white beady growth was also evident. In the badly damaged portions of the bale the musty smell had given place to a distinct winy odour.

Bale No. 4. Total moisture content 26 per cent.

This bale was even more completely damaged than No. 3. The fibre was very weak: and there was comparatively little of the mould but correspondingly more of the white growth; moreover the smell was not musty but rather winy throughout. The high temperature of the bale shows fermentation to be still in active progress.

Bale No. 5. Total moisture content 27 per cent.

Bale completely damaged: very like No. 4: mould spores very common but white growth also present with the same winy smell.

General observations on the baling tests.

Excepting in the bales containing 35 per cent. water, none of the fibre in any of the last three series of tests has been seriously discoloured: this is particularly true of the fibre in the bales in the third series, which suffered "heart damage" with only 25 per cent. to 27 per cent. of water. The result of the latter series of tests is to confirm the conclusion drawn from the second series, *viz.*, that given a higher temperature and a longer time, a smaller percentage of water than 29 per cent. would suffice to produce "heart damage." This has actually proved to be the case, and, although, judging from the time at which a rise of temperature began, the contents of bale No. 4

might have been more resistant to the damage than Nos. 3 and 5, the ultimate results were very concordant. This, and the smallness of the increments of moisture, justify us in concluding that "heart damage" is likely to occur in *pucca* bales when the total moisture content, estimated by drying the fibre at 221° F. (105° C.) as previously described, exceeds 25 per cent. The latter figure would probably correspond to something between 10 per cent. and 15 per cent. if, as is common in trade circles, the moisture were only estimated by sun-drying (*vide* pp. 39-40).

PART III.—LABORATORY EXPERIMENTS.

It now became necessary to ascertain, by experiment, the maximum percentage of moisture which can be taken up by jute fibre, when exposed to a damp atmosphere of known humidity, for a definite time and at a constant temperature, and to compare the result thus obtained with the approximate lowest percentage moisture content which the baling tests indicated as sufficient for the development of "heart damage." In this way definite information was obtained regarding the possibility of the occurrence of "heart damage" in jute, which, having been properly dried at the time of extraction, has subsequently only been subjected to legitimate atmospheric moisture conditions. The latter, it is hardly necessary to state, do not include exposure to rain or to night dews.

In discussing this aspect of the question, it is advisable first of all to give a definite meaning, in percentage figures, to the terms "normal moisture content," "sound dry jute," and "air dry jute", and in this connection the following quotation will be found apposite:—

N.B. It is perhaps necessary to repeat here what was said on page 39, *viz.*, that all moisture percentages quoted in this paper have, unless a definite statement is made to the contrary, been obtained by drying the sample in an oven at, or above, the temperature of boiling water (100° C. or 212° F.). These percentages are therefore higher by 10 per cent., more or less, than those commonly used in trade circles, which are obtained by drying in a hot sun instead of in an oven.

TABLE I.*

No. of samples	Date of experiment	Source of fibre	Percentage of moisture	Remarks, <i>i.e.</i> , notes sent with the samples
1	14th Nov., 1904	Through Messrs. Ralli Bros. of Serajganj	11.22	} Described as "dry."
2	Ditto	Ditto	10.94	
3	Ditto	Ditto	10.88	
4	Ditto	Ditto	10.95	

* "General Report on Jute in Bengal for 1904-5," by R. S. Finlow.

TABLE I—*concl'd.*

No. of samples	Date of experiment	Source of fibre	Percentage of moisture	Remarks, <i>i.e.</i> , notes sent with the samples
22	20th Nov., 1904	Through Messrs. Landale and Clark of Serajganj	15.06	"Dry jute."
26	Ditto	Ditto	15.10	"Dry."
28	3rd Dec., 1904	Through Messrs. Ralli Bros. of Serajganj	11.33	"Northern Bengal dry."
29	Ditto	Ditto	12.81	"Serajganj dry."
31	Ditto	Ditto	11.21	"Dowrah dry."
33	Ditto	Ditto	16.88	"Desi dry."
36	Ditto	Ditto	15.47	"Dacca dry."
39	Ditto	Camperdown Press, through Assistant Director of Agriculture, Bengal	12.11	"Narayanganj dry."
43	Ditto	Ditto	11.08	"Sound dry."
41	Ditto	Ditto	20.85	"Little wet."
60	Ditto	Central Jute Mills, through Assistant Director of Agriculture, Bengal	15.09	"Sound."
66	Ditto	Ditto	12.01	"Sound dry, Dacca."
68	Ditto	Ditto	11.14	"Sound dry, Rangpur."
70	Ditto	Ditto	13.45	"Good sound jute, Northern Bengal."
73	Ditto	Ditto	11.95	"Good sound jute, Khulna."

"The following results¹ were obtained from samples of damp jute collected at the same time and places as the above: they are included for information as well as by way of contrast. All the samples were taken in the open market where they were exposed for sale."

TABLE II.

No. of samples	Date of experiment	Source of fibre	Percentage of moisture	Remarks, <i>i.e.</i> , notes sent with the samples
5	14th Nov., 1904	Through Messrs. Ralli Bros. of Serajganj	29.21	Described as "wet."
6	Ditto	Ditto	31.33	
7	Ditto	Ditto	33.80	
8	Ditto	Ditto	30.46	
9	Ditto	Ditto	54.03	"Wet and sanded." N.B. Sand was not estimated.
10	Ditto	Ditto	32.62	
11	Ditto	Ditto	45.26	
12	Ditto	Ditto	43.98	
13	Ditto	Ditto	24.24	"Damaged."
14	Ditto	Ditto	37.74	
15	Ditto	Ditto	34.22	
16	Ditto	Ditto	24.77	
18	19th Nov., 1904	Ditto	55.17	These four samples were selected as being particularly bad instances of watering.
19	Ditto	Ditto	54.21	
20	Ditto	Ditto	46.32	
21	Ditto	Ditto	49.78	

¹ Loc. cit.

TABLE II.—*concl'd.*

Number of samples	Date of experiment	Source of fibre	Percentage of moisture	Remarks, <i>i.e.</i> , notes sent with the samples
23	20th Nov., 1904	Through Messrs. Landale and Clark of Serajganj	48.42	"Wet."
24	Ditto	Ditto	42.19	
25	Ditto	Ditto	33.64	
27	Ditto	Ditto	35.41	
30	3rd Dec., 1904	Through Messrs. Ralli Bros. of Serajganj	40.77	"Northern Bengal wet."
32	Ditto	Ditto	38.29	"Dowrah wet."
34	Ditto	Ditto	38.22	"Serajganj wet."
35	Ditto	Ditto	48.37	"Desi wet."

"The following samples were sent as being typical of dry fibre, in order that some idea might be obtained of the amount of moisture absorbed by jute fibre from the atmosphere in the rainy season. They were collected during the latter part of September, 1905, when the humidity, as well as the temperature, being high, the amount of moisture vapour present in the air would be correspondingly great."

TABLE III.

Number of samples	Date of experiment	Source of fibre	Percentage of moisture	Remarks, <i>i.e.</i> , notes sent with the samples
75	8th Oct.	Through Messrs. Landale and Clark of Serajganj	14.2	...
76	Ditto	Ditto	15.7	...
77	Ditto	Ditto	15.4	...
78	Ditto	Ditto	11.8	...
79	Ditto	Ditto	13.0	...
80	Ditto	Ditto	15.7	...
81	Ditto	Ditto	15.3	...
82	Ditto	Ditto	14.6	...
83	Ditto	Ditto	13.0	...
84	Ditto	Ditto	12.4	...
85	Ditto	Ditto	12.1	...

"The results given below are for samples which had been kept at Pemberandah (Bihar) for some time. When the last two estimations in the table were made, the weather was hot and dry. They show, by comparison with the figures in the previous table, that the amount of moisture in a genuine sample of fibre varies considerably according to the temperature and hygroscopic condition of the atmosphere."

TABLE IV.

Sample	Date	Percentage of moisture
A	5th February, 1905	10.91
B	Ditto	10.71
C	16th February, 1905	10.27
D	17th February, 1905	10.51
E	26th February, 1905	9.94
F	3rd March, 1905	8.01

These figures, representative as they are, indicate that from 15 per cent. to 17 per cent. is about the maximum amount of moisture which jute is likely to absorb under normal circumstances, and no one who has handled jute would have any hesitation in describing a sample of fibre containing more than 18 per cent. of moisture as "damp." It now remains to compare these percentages with the results of actual experiments, and the following further quotations¹ shew the effect of exposing dry samples of fibre to an atmosphere whose temperature and humidity are known:—

"To do this, the sample was placed in the upper perforated shelf of a water oven, the temperature of which was regulated to within a range of about $1\frac{1}{2}$ degrees by a thermostat. Inside the oven also was a wet and dry bulb thermometer, to indicate the degree of saturation of the atmosphere to which the sample was exposed. A small flat dish containing water was placed on the bottom shelf of the oven, so that the moisture absorbed from the air by the fibre might be replenished. The oven had two doors, the inner one being of glass, so that the hygrometer could be read without opening the oven."

TABLE V.

Showing the amount of moisture absorbed by samples of jute fibre from an almost saturated atmosphere at a high temperature.

Experiment	Temperature (degrees Fahrenheit)	Difference between readings of wet and dry bulbs (degrees Fahrenheit)	Approximate percentage humidity of atmosphere in oven	Time of exposure (hours)	Percentage of moisture found in fibre
1	92.0	1.0	96	48	16.70
2	91.0	1.0	96	48	16.23
3	92.0	2.0	94	48	16.66
4	92.3	1.3	94	24	15.26
5	92.0	1.0	96	48	16.35
6	93.0	1.0	96	48	16.82
7	94.0	1.2	95	67	17.28
8	93.0	0.5	98	144	17.65
9	93.0	1.0	96	96	16.65
10	94.0	0.5	98	144	17.50

¹ *Loc. cit.*

It thus appears that, after exposure for a time varying from 24 hours to 144 hours (1—6 days) in an atmosphere whose temperature is over 90° F. (32·5° C.) and whose percentage humidity is over 95, jute fibre absorbs less than 18 per cent. of water. These conditions approximate to—they are, if anything, damper on the whole than—the average of those prevailing, for any such prolonged period as four days, even in the rainy season, in India.

In the course of the years following the publication of the above figures, other work on the same lines has been carried out as opportunity offered. The latter results are about to be published in a separate note; but those of them which refer to jute are included here for the sake of completeness.

It has been seen that, in the early experiments, the fibre was exposed to an atmosphere which was approximately saturated with moisture vapour; nevertheless conditions of absolute saturation were never obtained. The first experiments, as has already been stated, were carried out in a jacketted oven with double doors. Later a Hearson's cool incubator was used, and water in flat-bottomed dishes and screens of wetted filter paper were introduced, to aid the saturation of the atmosphere as far as possible. Even these measures did not produce a completely saturated atmosphere as the following copy of a record card indicates:—

TABLE VI.

Jute.

Date	Hour	Dry bulb	Wet bulb	Difference	Relative humidity
10th May, 1908	10 A.M.				
Ditto	10.30 A.M.	75·7° F.	74·0° F.	1·7° F.	92·5 per cent.
Ditto	4 P.M.	75·5° F.	74·3° F.	1·2° F.	94·5 "
11th May, 1908	7.30 A.M.	74·9° F.	74·2° F.	0·7° F.	97·0 "
Ditto	2 P.M.	75·7° F.	75·0° F.	0·7° F.	97·0 "
Ditto	10 P.M.	75·1° F.	74·5° F.	0·6° F.	97·4 "
12th May, 1908	10 A.M.	75·4° F.	74·8° F.	0·6° F.	97·4 "
Ditto	9 P.M.	75·0° F.	74·4° F.	0·6° F.	97·4 "
13th May, 1908	10 A.M.	75·4° F.	74·8° F.	0·6° F.	97·4 "
Ditto	11 A.M.	Samples taken out.			

In this case there were six samples of fibre weighing from 2·5 gm. to 4·7 gm., and the respective moisture contents after exposure as above were:—

(a) 23·02 per cent.

(b) 22·39 "

(c) 22·69 "

(d) 22·85 per cent.

(e) 23·07 "

(f) 22·86 "



i.e., mean absorption of water vapour after 3 days' exposure to an atmosphere whose temperature was 75° F. (24° C. approximately) and whose relative humidity was 97.5 per cent. . . 22.81 per cent.

Similar experiments at the same temperature, but for longer periods, gave absorption figures as follows:—

TABLE VII.

Mean absorption of water vapour after 6 days . . 24.43 per cent.

Ditto ditto 12 days . . 24.95 „

In more recent experiments, detailed below, the following procedure was adopted to secure a saturated atmosphere at a constant temperature. About 2 gm. of the fibre was placed in a small beaker, which was put in a wide-mouth glass-stoppered bottle containing a little water. The bottle was closed and kept in a Hearson's incubator at constant temperature. It is assumed that saturated conditions were realized in this way, but though decidedly higher results have been obtained for longer periods, short exposures do not seem to have produced materially greater absorption than before.

The following copy of a record card shows the variations of the side thermometer in the incubator.

TABLE VIII.

Jute, 7 bottles.

Each sample weighed approximately 2 gm.

Date	Time	TEMPERATURE		REMARKS
		Centigrade	Fahrenheit	
11th July, 1916 ..	4.30 P.M.	23.00°	73.40°	Samples put in.
12th July, 1916 ...	7.40 A.M.	23.00°	73.40°	One sample taken out.
13th July, 1916 ...	7.30 A.M.	23.00°	73.40°	Ditto.
14th July, 1916 ...	7.20 A.M.	23.25°	73.85°	One sample taken out, during which temperature rose to 23.75° C.
Ditto	9.45 A.M.	23.75°	74.75°	
15th July, 1916 ...	7.30 A.M.	23.25°	73.85°	One sample taken out.
Ditto	4 P.M.	23.50°	74.30°	Temperature constant all day.
16th July, 1916 ...	7 A.M.	23.25°	73.85°	One sample taken out.
Ditto	3 P.M.	23.00°	73.40°	Ditto
17th July, 1916 ...	7.30 A.M.	23.25°	73.85°	Ditto
18th July, 1916 ...	7.30 A.M.	23.25°	73.85°	Ditto

The respective moisture contents of the samples, taken out each day during the progress of the experiment just described, were as follows :—

TABLE IX.

Temperature 23° C. (73·40° F.)

Time of exposure				Percentage of moisture found
Original sample	...	...	...	13·5 per cent.
13 hours	...	...	...	17·7 "
37 " (1½ days)	...	...	...	21·1 "
61 " (2½ " )	...	...	...	21·8 "
105 " (4½ " )	...	...	...	23·4 "
139 " (5½ " )	...	...	...	25·6 "
163 " (6½ " )	...	...	...	25·8 "
187 " (7½ " )	...	...	...	27·0 "

These figures show a distinct increase in the amounts of water absorbed by the fibre from a saturated atmosphere, as compared with one which is not quite saturated.

Experiments were carried out with similar weights of fibre, *viz.*, 2 grm. approximately, at different temperatures ranging from 16° C. (60° F.) to 36° C. (96·8° F.); and the respective results for these latter temperatures are given below:—

TABLE X.

TEMPERATURE 16° C. (60° F.)				TEMPERATURE 36° C. (96·8° F.)			
Time of exposure		Percentage of moisture found		Time of exposure		Percentage of moisture found	
Original sample	...	12·7 per cent.		Original sample	...	13·0 per cent.	
12 hours (½ day)	...	16·5 "		1 day	...	22·2 "	
26 " (1½ days)	...	19·0 "		2 days	...	24·4 "	
60 " (2½ ")	...	20·2 "		3 " "	...	26·6 "	
84 " (3½ ")	...	21·9 "		4 " "	...	27·2 "	
132 " (5½ ")	...	25·8 "		5 " "	...	27·9 "	
180 " (7½ " )	...	.....		6 " "	...	27·8 "	
204 " (8½ ")	...	26·1 per cent.		.....	...	.....

The following results with larger quantities of fibre are interesting: none of the weights is large, yet it seems that the bulk of the fibre, represented by half an ounce weight (15 grm.), has not absorbed its maximum proportion of water vapour even after 6 days.

TABLE XI.

Temperature 19°—20° C. (68° F.)

Weight of sample in gramm.	Time of exposure	Percentage of moisture absorbed
1.9712	6 days	26.4 per cent.
2.3438	"	26.0 "
2.7454	"	25.2 "
15.9320	"	20.8 "
17.6820	"	20.6 "

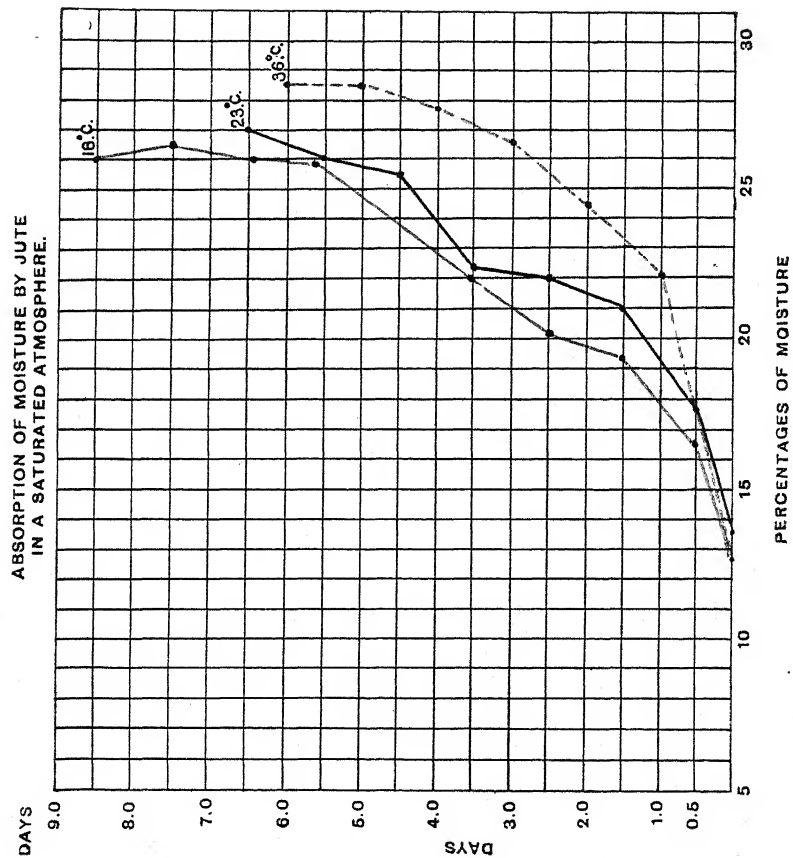
DISCUSSION OF RESULTS.

Taken together, the above results furnish sufficient data to discuss the possibility of "heart damage" occurring in jute, which has obtained its moisture in a legitimate way only, *viz.*, by absorption from a damp atmosphere.

The figures are very concordant, and they show that, at a temperature of 36° C. (96.8° F.) and in a completely saturated atmosphere, the maximum absorptive capacity of jute fibre for water vapour is less than 28 per cent.; at lower temperatures (23° C. and 16° C.), it would seem to be slightly, but actually and proportionately, less, and it is interesting to note that the absorption seems to be more rapid at the higher temperatures than at lower ones.

Graphic representation of the results for all three temperatures is given in the accompanying set of curves.

The baling tests described in the first part of this note indicate that about 25 per cent. of moisture is sufficient to allow the development of "heart damage" in jute. At first sight, therefore, the fact that the fibre is, under certain conditions, actually capable of absorbing more than this amount of moisture vapour, seems to indicate that "heart damage" may sometimes be caused by natural moisture. Reflection, however, reminds us, firstly, that the atmospheric conditions under which jute fibre can absorb 25 per cent. of moisture are those of absolute saturation; and, secondly, that even in such a constantly saturated atmosphere, over four days are required for the absorption of 25 per cent. We are further reminded that if the humidity conditions fall short of saturation by even so much as 2 or 3 per cent., the absorption capacity of the fibre falls well below the minimum of 25 per cent. necessary for the production of "heart damage" even after 6 days' exposure.



Remembering these facts, and bearing in mind also not only how comparatively rare it is for conditions of absolute saturation to prevail at all; but also how unprecedented would be the meteorological conditions which would induce constant saturation for a period of four days, we see how improbable it is that any genuine sample of fibre would be found containing even so much as 20 per cent. of moisture, let alone 25 per cent. This view is supported by the results detailed in Table V. They show that no sample absorbed as much as 18 per cent. of moisture after four days in a closed vessel, whose atmosphere was about 95 per cent. saturated. It has already been pointed out that such conditions approximate to (they are, if anything, decidedly damper than) the average of those prevailing for any such prolonged period as four days in the rainy season in India.

It is difficult, even in the laboratory, to secure absolute saturation, excepting in so confined a space as a tightly corked bottle, or its equivalent, and it is still more difficult to maintain such conditions over any long period. It is certain that such conditions never exist in places where jute is stored.

The contents of Table X are important in this connection. They show that unless the quantity of the fibre is very small, and also very loosely packed, the interior of the bulk of fibre cannot absorb a maximum amount of water vapour in a reasonable time. Even so small a quantity as half an cunce (15 gm.) only absorbed 20 per cent. of moisture from a saturated atmosphere in 6 days, as compared with 26 per cent. taken in by the smaller bulk of 2 gm. Such results prove that, even in a saturated atmosphere, provided considerable condensation does not take place, the passage of moisture into the interior of any large bulk of fibre, loose or baled, would proceed only slowly. Thus even if a thin outer layer absorbed the maximum amount of moisture, the average moisture contents of the whole bulk would still be only slightly affected.

The conclusion is therefore inevitably reached that it is virtually impossible for genuine dry jute, either loose or after baling, to absorb sufficient moisture vapour from the atmosphere to allow of the development of "heart damage."

Table XI is further interesting in connection with the question of "ship damage" (pp. 43 & 44).

"Ship damage" is well known and is the cause of numerous disputes and arbitrations between shippers in India and importers in Europe. The result of its action on jute is the same as that of "heart damage," and both are

probably produced by the same organism. Both forms of deterioration are due to excessive water, but it is generally recognized that "heart damage" commences in the centre of the bale, and that it only takes place when the fibre is unduly damp at the time of baling. On the other hand, dampness of the fibre at the time of baling is not a necessary condition for the production of "ship damage": indeed it is commonly held that, given insufficient ventilation during sea transit, even perfectly sound jute may suffer "ship damage." It has been shown (*vide* 2nd series of *pucca* baling tests, page 44), that the water absorbed during temporary immersion of a bale of dry jute was sufficient to bring the average moisture content of the fibre in the bale to 25 per cent., the approximate minimum moisture percentage necessary for the production of "heart damage" in the centre of the bale. Nevertheless the water did not penetrate to the centre of the bale, which was dry and sound after 6 weeks. On the other hand, the fibre in the outer 2 or 3 inches of the bale had lost all tensile strength. This is "ship damage."

Table XI shows us that moisture vapour takes much longer to penetrate to the centre of even a small bulk of jute, than to be absorbed by a loosely spread layer of fibre; and so long as actual condensation does not take place, its absorption beyond the outer layer of a large quantity of fibre, such as a bale, would proceed only slowly. Nevertheless, if the space were confined and the atmosphere saturated, as in a closed bottle with water at the bottom (*vide* page 54), or, on a large scale, in the hold of a ship, which is not dry and also imperfectly ventilated, the absorption of moisture by bales of fibre in the hold would always increase, even though the fibre does not come into actual contact with water in the hold. Ultimately the moisture might accumulate sufficiently in, and penetrate deeply enough into, some of the bales to cause decay of the outer layers of fibre. This again is "ship damage."

In the hold of a damp and badly ventilated ship, continual evaporation of water during the heat of the day tends towards constant saturation of the air in the hold with moisture. A part of this moisture would, as shown above, be absorbed, as vapour, by fibre in the hold; but diurnal or climatic changes of temperature would also involve more or less frequent condensation of moisture on the surface of some of the bales. In such circumstances the rate of penetration of moisture into the interior of a bale would be more rapid than could be induced by mere absorption of water vapour from a moist atmosphere; moreover, the greater the number of condensations, the more rapid would be the penetration, and consequently the incidence of "ship damage." Ultimately the condition of a bale subjected to such treatment would probably approximate to that of

bale No. 6, already referred to (*vide* pages 43 & 44), which was immersed in water. In all this we have a reasonable explanation of "ship damage" and of the widely held opinion that the conditions existing in the hold of the ship during transit to Europe are connected with its occurrence. The latter opinion is supported by the fact that shipping lines differ considerably in their respective reputations in regard to the percentage of sound bales which they deliver. It is possible, however, that such a reputation may be partly due to other factors, besides careful use of the ventilators during the voyage; for instance, the efficiency of ventilation is certainly affected by the method of stowing of the bales in the hold of the ship, and it is held that carelessness, or ignorance, in this matter may render good ventilation impossible. On the other hand, it must obviously be more difficult to ventilate properly a hold containing damp jute; and it is also reasonable to suppose that if sound dry jute is stowed alongside of damp jute, the former will be more liable to suffer "ship damage" than if the hold only contains dry fibre.

PART IV.—SUMMARY.

(1) "Heart damage" is so called because it appears first in the centre of the mass of fibre in which it occurs.

(2) Dry jute never suffers "heart damage"; but when damp jute is baled, a rise of temperature up to a maximum of about 40° C. (104° F.) takes place in the interior of the bale. This is due to the action of thermophilic bacteria which attack the cellulose constituent of the fibre and apparently hydrolyse it. The result is that a large proportion—sometimes approaching 60 per cent.—of such damaged fibre becomes soluble in water, or in dilute acid, or alkali. The fibre also loses all tensile strength and becomes useless for spinning.

(3) Bacterial cultures have been isolated, which produce the typical characteristics of "heart damage" in the laboratory.

A mould, identified by Dr. Butler, Imperial Mycologist, as *Aspergillus fumigatus*, has been found in practically every bale of "heart damaged" jute examined. The mould has apparently nothing to do with the production of the damage, but lives on the degradation products of the cellulose. Dr. Butler reports that the mould has pathogenic properties and that it has been known to cause deafness in man, as well as a disease of the lungs similar to phthisis. Those who are in the habit of baling damp jute would do well to bear this fact in mind.

(4) The more tightly the fibre is packed, i.e., the greater the pressure employed, the lower the proportion of water required for the development of "heart damage" is. Thus small masses of loose jute will probably not suffer damage with less than 45 per cent. to 50 per cent. of moisture.

It has been ascertained by actual experiment that *kutcha* bales (3½ maunds or about 280 lb.) require over 30 per cent., but that *pucca* bales (5 maunds or 400 lb. approximately), which are subjected to a pressure of 2 tons to the square inch, will develop damage with only about 25 per cent. water.

In this connection it is interesting to note that, at the pressure used in making *pucca* bales, fibre containing 25 per cent. of moisture just begins to

exude a little water. Below this figure no water is squeezed out by the pressure.

Percentages of moisture are estimated by drying the damp fibre to constant weight in an oven at a temperature of about 105° C. (221° F.)

(5) Jute exposed for 100 hours to conditions considerably more favourable than an average for those prevailing during the rainy season in Bengal, *viz.*, a temperature of 33° C. (92° F.) and a humidity of about 95 per cent., absorbed a maximum of 17.5 per cent. of moisture. This is 7½ per cent. below the minimum required for the development of "heart damage" in *pucca* bales.

(6) Jute fibre can be made to absorb about 27 per cent. of moisture, but only in a reasonable time when in very small quantities, or in thin layers loosely spread, and when the atmosphere is completely saturated with water vapour. Even under these favourable conditions a period of about four days (100 hours) is required for the absorption of 25 per cent. moisture.

(7) Such a combination of conditions never occurs in practice, and the incidence of "heart damage" in genuine jute may be regarded as impossible.

Fibre which has been improperly dried after extraction, or which has been exposed to night dews, or otherwise watered, is not regarded as "genuine."

(8) "Ship damage" of baled jute is similar in its effects to "heart damage" and is probably produced by the same class of organisms. "Ship damage", however, appears first in the outside layers of the bale and not in the interior of it as happens with "heart damage."

It is tentatively shown how bales of sound dry jute stowed in a damp and badly ventilated ship's hold might absorb sufficient water, through repeated condensations of moisture from the air, to enable "ship damage" to ensue.

Dacca:

3rd July 1917.

APPENDIX I.

(a) REPORTS, AND A NOTE, BY DR. BUTLER, IMPERIAL MYCOLOGIST,
PUSA, ON *ASPERGILLUS FUMIGATUS*, FRES.

No. 60 OF 1917-18.

FROM

DR. E. J. BUTLER, M.B., F.L.S.,
Imperial Mycologist, Agricultural Research Institute, Pusa,

TO

THE FIBRE EXPERT TO THE GOVERNMENT OF BENGAL, DACCA.

Dated Pusa, Bihar, the 7th May, 1917.

SIR,

I HAVE the honour to report that I have received the culture of a mould from damaged jute, sent with your letter dated 28th April, 1917, in good condition.

The fungus is *Aspergillus fumigatus*, Fresenius, a cosmopolitan species common on plant remains and industrial products, especially under conditions of high temperature, and also not rare as a parasite of man and animals (lungs, ear, etc.).

The optimum temperature of this fungus is from 37° to 40° C., so that it may be expected to appear where fermentation has led to heating in the bales.

I have the honour to be,

Sir,

Your most obedient servant,

(Sd.) E. J. BUTLER,

Imperial Mycologist.

No. 74 OF 1917.

FROM

DR. E. J. BUTLER, M.B., F.L.S.,

Imperial Mycologist, Agricultural Research Institute, Pusa,

TO

THE FIBRE EXPERT TO THE GOVERNMENT OF BENGAL,

GOVERNMENT FARM, DACCA.

Dated Pusa, Bihar, the 12th May, 1917.

SIR,

I HAVE the honour to report, in continuation of my letter No. 60, dated the 7th May, 1917, that the incubation tests with the mould from damaged jute have confirmed the identification of the fungus as *Aspergillus fumigatus*, Fres.

It grows much more vigorously at high temperatures, approaching 40° C. (104° F.); scarcely at all at 22° C. (72° F.)

The young cultures are typical in every respect of the species as described in Europe.

As its interest lies in its high optimum temperature and its pathogenicity to man, can you let me know if damaged jute, such as that from which it was taken, heats; and also whether cases of lung or ear disease are reported from the jute mills where such jute is handled?

I have the honour to be,

Sir,

Your most obedient servant,

(Sd.) E. J. BUTLER,

Imperial Mycologist.

NOTE ON *ASPERGILLUS FUMIGATUS*, FRESENIUS.

BY

E. J. BUTLER, M.B., F.L.S.

Imperial Mycologist.

Aspergillus fumigatus Fres. is a cosmopolitan mould, first described by Fresenius from the air cavities of a bustard in 1841. It has attracted attention chiefly from its not infrequent occurrence in the body cavities of man and

animals (horse, cow, pigeon, domestic fowl, turkey, etc.), and its proved pathogenicity to many small animals when inoculated into the blood stream or the peritoneal cavity, or by inhalation into the lungs. In man it is best known as an ear parasite, sometimes causing complete deafness. It attacks also the human lung, producing a type of disease often difficult to distinguish, without the aid of the microscope, from phthisis. Less often it has been found in the nasal cavity and on wounded surfaces, especially in the eye. These infections are most commonly observed amongst persons engaged in certain occupations; those of the lung, for instance, being prevalent amongst the pigeon fatteners and hair combers in Paris.

As a saprophyte it is found on vegetable débris, dead leaves, dry fodder, and on seeds and grains. It has also been obtained from fermenting tobacco leaves; from potatoes, bread, etc., in warm incubators; and on woollen fabrics. Recently it has been proved to be a common soil dweller in parts of the United States (Cornell) and it also occurs in the soil at Pusa. It has not previously been reported in India on vegetable matter, no doubt because it has not been looked for, since it is exceedingly unlikely to be confined to jute. But it only attracts notice, as a rule, when it becomes a human parasite, and this is relatively rare except amongst those exposed to repeated infections. The pigeon fatteners of Paris feed their pigeons with seeds and grain from their own mouths, and such seeds and grain often bear spores of the fungus. So also the hair combers use contaminated rye flour for powdering the hair while working at it. It is evident that there is a possible danger to jute mill workers who handle contaminated jute, and enquiries have been instituted to ascertain whether cases of infection have been observed.

The characters of the fungus are as follows: The growth is whitish when young, but rapidly turns light green and then olive or dark green as the spores mature. The mycelium is colourless, the individual threads being $2/1000$ to $3/1000$ mm. in diameter and not much raised above the surface on which they are growing. As the spores develop the growth becomes more woolly or velvety, and green, at first in patches and then uniformly. The spores are borne on short, unbranched stems, $1/10$ to $3/10$ mm. in height by about $6/1000$ mm. thick, the top being swollen into a club-shaped head, some $15/1000$ mm. across. On the upper part of this, a layer of closely crowded, parallel spore-stalks arise, all pointing upwards and each terminating in a chain of spores. The individual spore-stalks are unbranched and shorter than the diameter of the club-shaped head. The spore chains are long and often closely pressed together into a long cylindrical green head. The spores are colourless or faint green singly, round, smooth, and only $2/1000$ to $3/1000$ mm. in

diameter. A second spore-form, the product of sexual reproduction, has been reported, but it is open to some doubt whether it really belongs to *Aspergillus fumigatus*. In it the spores are borne in little sacs in the manner characteristic of the fungus class *Ascomyces*. This stage is authentic in several other species of *Aspergillus*.

The species is a lover of heat. It grows best at temperatures of 37° to 40° C., and doubtless this character aids it in its attacks on warm-blooded animals and man. In Pusa it was found scarcely to grow at all at a temperature of 22°.

(b) LETTER FROM THE HON'BLE SIR ARCHY BIRKMYRE.

6, Clive Row,
Calcutta, 7th June, 1917.

MY DEAR FINLOW,

I DULY received your D. O. No. 92-H-4 of 25th ultimo. I am sorry that pressure of work has prevented me replying sooner.

I was much interested in the quotation you give from Dr. Butler's letter regarding the results of investigation tests with the mould from damaged jute.

You ask me if I can give you any information, either from my own experience or by reference to the Jute Mills Association, regarding the incidence of pneumonia or ear disease amongst employees in jute mills. Pneumonia is certainly not an uncommon disease amongst jute workers, but I do not think it can be connected in any way with the handling of damaged jute. As a matter of fact, the mills here only use *pucca* bale jute to a very small extent, and I do not think there is any likelihood that "heart damage" would occur in *kutchra* pressed bales as used by the local mills.

It is quite possible that the same results might be obtained from jute which had been packed wet and had rotted as those obtained from mould in "heart damaged" samples, but the extent to which this damage takes place in the local mills is seldom in any considerable volume, and when wet parcels are delivered, they are usually put into consumption at once.

Yours sincerely,
(Sd.) ARCHY BIRKMYRE.

APPENDIX II.

CORRESPONDENCE WITH REPRESENTATIVES OF THE JUTE TRADE IN CALCUTTA ON THE SUBJECT OF "HEART DAMAGE":—

(a) Letter from Mr. D. L. Millar (Messrs. D. L. Millar & Co.).

10, Clive Row,
Calcutta, 30th April, 1917.

DEAR SIR,

I HAVE read with much interest the papers you left on Saturday forenoon on the subject of "heart damage" and "ship damage."

The various experiments have been exhaustive and the conclusions sound; these have been gone into so thoroughly that little is left me to remark upon, except to confirm that, so long as jute is shipped sound, there is no fear for the internal condition.

It would be interesting to test the fibre of *C. olitorius* as against *C. capsularis*, the former in both *bogi* and *desi* varieties, as the *olitorius* appears to be able to stand more moisture than the other.

Regarding "ship damage" it is perfectly correct to assume that quite sound dry jute may be "ship damaged" by imperfect ventilation causing condensation, but a good deal depends on the season at which the jute is shipped, and whether sound dry jute is carried in proximity to, or in the same hold as, damp baled jute; where condensation takes place the top tier of bales naturally suffers most and damage is also more likely to take place where contact with beams or stanchions is made.

It is not fair to assume that all "ship damage" is the fault of the ship, it may be partly due to the condition of the jute aggravated by bad ventilation; a well ventilated and properly stowed hold on the other hand might be comparatively free from "ship damage" in similar conditioned jute.

Yours faithfully,
(Sd.) D. L. MILLAR.

(b) Letter from Mr. P. E. Suttie (Messrs. Sinclair Murray & Co.).

5-1, Royal Exchange Place,

(Post Box No. 8).

Calcutta, 5th May, 1917.

MY DEAR FINLOW,

WITH many thanks I am returning under registered cover your memorandum on "heart damage" in jute. You know a great deal more about this matter than I do, and, I am afraid, there is nothing I can tell you from experience that would be of any assistance to you. To tell you the truth, I have had very little experience of damage from moisture. In all our places we handle only jute that is comparatively dry; in fact, dry enough to avoid liability to damage.

There is just one point on which I would express an opinion, and that is with reference to Bogi or Tossa jute in comparison to White jute.

On page 14 you say that you found indications that Bogi or Tossa jute was less liable to suffer damage than the White jute fibre; but I think this is not the generally accepted idea in the trade. It is usually considered that Bogi or Tossa will damage much more quickly and to a more serious extent from a certain percentage of moisture than White jute will.

Not long ago I was at one of the mills up the river, when the manager opened in my presence a bale which I understood to be of Tossa or Bogi, and which had gone absolutely rotten, although, so far as the mill people were aware, the moisture contained in the bales, at the time they were received at the mill, had not been considered excessive. This was a *kutch* bale and, when opened, the jute had the appearance of being undamaged. It was only when one tried to lift a part of it that it was found to crumble into powder. I may mention that the bales in question had been stored in the mill godown for a considerable period, a year or two if I remember rightly.

Also, I know that our people in the mofussil are much more afraid of packing up Bogi or Tossa in a damp state than they are in the case of White jute.

I would suggest that you should make some comparative experiments with Tossa and White jute to satisfy yourself on this point. It could be quite easily done.

There is another point in this connection that I might suggest. We find that on the whole the Tossa contains, or appears to contain, a higher percentage of moisture than White jute does as a rule; but whether this is because more

moisture is added to the Tossa or Bogi, or because the Tossa fibre naturally absorbs moisture more readily than White jute, I am unable to say.¹ It is just possible that Tossa absorbs moisture more readily, because the moistening of jute is, in a great many cases, done under similar circumstances, that is to say, the jute is spread on the ground overnight and allowed to absorb the dew that falls on it during the night. My reason for supposing that Tossa more readily absorbs moisture is that not long ago I was arbitrating on a parcel of jute here in Calcutta. There were 10 bales which were opened for inspection; 9 of the bales were practically dry, in fact dry enough to be passed as in thoroughly good condition; but the tenth bale contained a large percentage of Bogi jute, and the moisture in that bale was decidedly excessive and was, beyond question, due to the presence of Bogi jute in the bale.

Then, there is one other point which I might suggest and about which I spoke to you when you were here last week, and that is that I have always been of opinion that jute, which has been insufficiently dried in preparation, will carry an excess of moisture with less liability to damage, than jute which has once been thoroughly dried and then wetted.

* * * * *

I am,

Yours sincerely,

(Sd.) P. E. SUTTIE.

¹ Experimental observations on this point indicate that White jute (*C. capsularis*) and Tossa or Bogi (*C. olitorius*) differ only very slightly, if at all, in their respective capacities to absorb moisture. [R. S. F.]

PREFACE.

At the present time the development of Indian industries is occupying the serious attention of the authorities.

The following pages consist of an attempt to give detailed information relating to a very important industry which has managed to survive in the face of many difficulties. We have been able, as a result of our work, to make certain definite recommendations for the improvement of this industry. India produces at least 300,000 tons of sugar per year from various palms. Bengal is said to produce about 100,000 tons of this quantity. European firms in Madras purchase about 25,000 tons of raw palm sugar for refining and distilling purposes annually; so that we have an industry the annual value of whose output in normal times is roughly 2½ million pounds sterling.

It would be difficult to find any other industry of like magnitude which has received so little investigation.

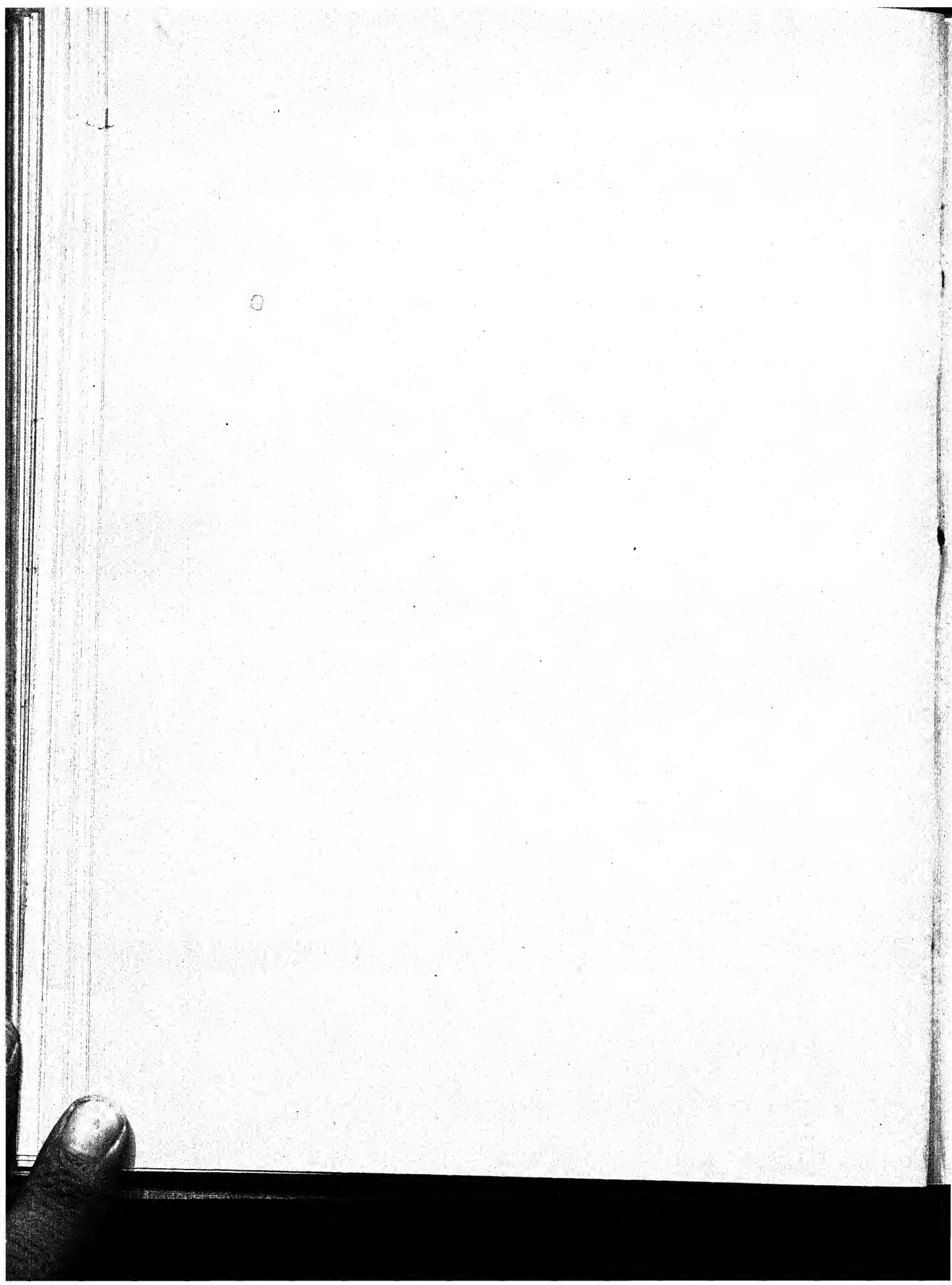
Owing to my having been placed on special duty in the United Provinces, the publication of the results of these experiments has been much delayed, and even then the results of some of the work done have had to be omitted.

It would be ungrateful of me if I did not again acknowledge the great help which Mr. E. G. Macleod, of Kotechandpur, Jessore, has continued to give us in our work.

H. E. ANNETT.

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EXPERIMENTS ON THE IMPROVEMENT OF THE DATE PALM SUGAR INDUSTRY IN BENGAL.

INVESTIGATIONS IN 1915-16.

BY

H. E. ANNETT, B.Sc. (Lond.), F.I.C., etc.,
Agricultural Chemist to the Government of Bengal,

GOSTA BEHARI PAL, M.Sc. (Cal.),

AND

INDU BHUSHAN CHATTERJEE, L. Ag. (Nag.),
Assistants to the Agricultural Chemist to the Government of Bengal.

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PART I. INTRODUCTION.

THE importance of various palm trees in India as a source of sugar has already been pointed out by one of us in a recent memoir.¹ That memoir was a preliminary general survey of the agriculture and chemistry of the date sugar industry in Bengal. A great deal of information was collected. Some preliminary recommendations were made for the improvement of the industry. Most of the work now to be described was performed during the cold weather of 1915-16, but it has had to be done in conjunction with other work.

It will not be out of place to recapitulate here some of the advantages of the palm tree as a source of sugar.

¹ Annett, H. E., Lisle, G. K., and Amin, Bhailal M. "The Date Sugar Industry in Bengal: An Investigation into its Chemistry and Agriculture." *Mem. Dept. Agric., India, Chem. Ser.*, vol. II, no. 6.

The yield of sugar is certain from year to year, and is not affected by drought or floods as is the case with sugarcane. Very little cultivation expense has to be incurred. A longer sugar-making season is possible with palms than with sugarcane.

The cost of production per maund of *gur* (raw sugar) is less in the case of the date palm and palmyra palm than it is in the case of sugarcane. This is witnessed by the fact that the pre-war price of palm *gur* was Rs. 3 to Rs. 3-8 per maund (82lb.), when cane *gur* was selling at Rs. 5 to Rs. 6 in the same district. The sugar content is more or less the same in the two cases. If the colour of the palm *gur* could be improved, it would probably fetch a better price.

The juice of the palm tree, if collected under careful conditions, is very pure and contains very little sugars other than cane sugar. In Bengal, under present conditions, the juice is not collected under good conditions. The work to be described will show how, in a simple manner, these conditions can be improved.

No crushing mills are required to obtain the juice. This would save a certain amount of capital expenditure in a large factory.

It would be only fair to point out here, however, that there is one big disadvantage, in that, in the case of the sugarcane, no fuel has to be purchased, the sugarcane megass, *i.e.*, the residue after crushing the juice out of the canes, being used as the source of fuel. One has to buy fuel in the case of the palm sugar industry, though the dried leaves cut off from the trees last for a month at the beginning of the season.

Attention has been paid in the present work to the fuel question.

One of the suggestions put forward in the memoir above quoted was that a Hadi process plant, capable of dealing with 60 to 100 mds. of juice per day, might be set up in the district, and that juice be purchased from the cultivators at 4 to 4½ annas per maund. A better quality of *gur* would probably be thus obtained, and it would probably pay to put in a centrifugal plant to produce sugar from the *gur*. In accordance with this suggestion, an up-to-date maple-sugar-making plant was imported from America. By means of this we at times made 3 to 3½ mds. of *gur* per day. Such a scheme would be unworkable in practice, however, unless the owner of the plant also had his own trees. Personal experience showed us that one is entirely at the mercy of the cultivator, and no amount of argument will persuade him to sell his juice at a reasonable rate. We were only able to get juice at 7 to 8 annas per maund, and at that rate the venture could only result in heavy loss. It must be

remembered, however, that the price of *gur* was much higher this season than at the time this suggestion was made.

It will be seen that a good deal of useful information has accumulated as a result of this last season's work.

The importance of improving the native industry has been kept chiefly in mind, but the possibility of the production of palm sugar on the factory scale has not been lost sight of.

PART II. TAPPING THE TREES.

It is considered advisable to describe again the process by which the juice is obtained from the wild date palm, since otherwise various terms would need explanation in the course of the text. The following account is taken from the previous memoir written by one of us.

The usual articles required for this work consist of (1) a rope (*dara*), 9 ft. long and 1 to 1½ inches thick, which is loosely tied round the operator and the tree, and by means of which a man can climb rapidly and safely; (2) a plaited palmyra leaf bag (the *thungi*), about 1 ft. deep, in which are carried the *daws*, spouts, and other articles, and to which are attached a wooden hook and two loops of string, the loops going round the waist of the man, and being tied in front, and the hook suspending an earthen pot; (3) a piece of canvas or goatskin (the *kolach*), 1 ft. wide, which is tied on the man's back to protect him from the rubbing action of the climbing rope; and (4) three *daws* (bill-hooks), one heavy and two lighter ones. (All the above are shown in Plate III of the memoir quoted.)

The tapping is a delicate operation, commenced in October and done in several stages. With the heavy *daws*, all the old leaves are cut off below the crown, and all the leaves from one side of it, leaving only a few at the top, the bases of the petioles and the sheaths being carefully removed (see Plate IV of the memoir referred to above). Then, with the lighter *daws*, the outer zone of the loose soft tissue is pared off in long slices, leaving only a thin covering of it over the sap-supplying inner zone, which corresponds to the woody zone in the older wood of all palms. Very great care must be taken not to expose this inner tissue at this stage, otherwise the tree is sure to rot and die, as often happens when the operation is entrusted to inexperienced hands. The experts at this work are called *saihis* or *gachis*. After this first operation the trees are given about 8 days' rest, by which time the fine covering of soft tissue gets a little hardened and

begins to crack. The second operation consists in removing this covering, great care being taken not to cut into the inner zone which is now for the first time simply exposed. Then comes a rest of 12 to 14 days, which brings us to the beginning of November. The *gachi*, as a rule, divides his trees into six convenient groups called *palas*, each containing 50 or 60 trees, the number which he can operate on in one day, 300 to 400 being the total number which one man can manage. Next, after midday, he cuts two eye-shaped notches, 3 to 4 inches long and about $\frac{1}{4}$ inch deep at the base, their lower sides being straight and converging to a point, below which a split bamboo spout is driven into the tree. About 3 or 4 o'clock in the afternoon an earthenware pot is suspended under the spout, and the juice which trickles down is collected. The pots are removed early next morning at 6 or 7 A.M. before the sun gets on them and the juice boiled into sugar. On the following night juice is again collected generally without renewing the cut, though the surface is as a rule cleaned with the hard stem of a palm leaf. A much smaller quantity is generally obtained than on the first night. On the third evening also more juice is, as a rule, collected; but it is only small in amount and of very poor quality. Each night's juice has a distinctive name given to it. That of the first night is called *jiran* (rest), of the second night *dokat* (second cut), and of the third night *tekat* (third cut). On the fourth and fifth nights no juice is collected. After six days the cut is renewed a little, and for three days juice is again obtained, being given the same names as before. The tapping process goes on in this way throughout the season. The first 2 to 3 weeks' supply is very valuable, for the *gur* produced from it, called *Nolen-gur*, has a very pleasant smell and is much appreciated by the consumers. It fetches a high price.

Of course it is not to be supposed that in all cases such a regular system of tapping is carried out. Sometimes the trees are cut for 2 to 3 days in succession, and sometimes they may be cut every fourth day; but such frequent tapping soon destroys the trees.

The *daws* (bill-hooks) require much attention. They are daily sharpened on a piece of dry wood sprinkled over with fine sand while the *daws* are new, but with dry potter's clay afterwards. They may even require tempering once or twice in a season. The tip is especially looked to. If too sharp and pointed, it cuts into the trees and injures them, sometimes fatally, and if too blunt, it tears the tissues, whereas a clean cut must be obtained.

The following plan illustrates the daily round of work in the garden :—

Order of tapping.

Days			Divisions of the garden			Cuts
1st day	..	..	1st portion	..	..	Jiran
2nd day	..	..	1st portion	..	..	Dokat
			2nd do.	..	..	Jiran
3rd day	..	..	1st portion	..	..	Tekat
			2nd do.	..	..	Dokat
			3rd do.	..	..	Jiran
4th day	..	..	1st portion	..	..	Rest
			2nd do.	..	..	Tekat
			3rd do.	..	..	Dokat
			4th do.	..	..	Jiran
5th day	..	..	1st portion	..	..	Rest 2nd day
			2nd do.	..	..	Rest 1st ..
			3rd do.	..	..	Tekat
			4th do.	..	..	Dokat
			5th do.	..	..	Jiran
6th day	..	..	1st portion	..	..	Rest 3rd day
			2nd do.	..	..	Rest 2nd ..
			3rd do.	..	..	Rest 1st ..
			4th do.	..	..	Tekat
			5th do.	..	..	Dokat
			6th do.	..	..	Jiran

As a rule there is no *dokat* or *tekat* juice in November. In December *dokat* juice as well as *jiran* is obtained. In January we have *jiran*, *dokat* and *tekat* juices.

Towards the end of January, and thence till the end of the season, the trees are slightly cut for *dokat* juice as well as for *jiran*. That is, they are cut on two successive nights, (1) for *jiran*, (2) for *dokat*. *Dokat* juice yielded from a surface cut afresh is called *dokat pocha*.

A fair amount of juice drops from the cut surface during the day. This is collected and is called *ola*. It is very poor in quality and is boiled into molasses which is sold for mixing with tobacco at 12 annas per maund¹ (*kutchu*). In normal cases the cut is renewed week after week until about the middle of March, by which time a very deep notch is made into the tree, reaching one-third or at times half through it. Each succeeding cut tends to go slightly higher up than the previous one. The next year's cut is made on the opposite side, but at a slightly higher level, the tree having grown in

¹ One maund (*kutchu*) = 60lb. roughly.

height in the meantime. This continued year after year gives the plant its characteristic zig-zag appearance. It is noticeable that trees are almost always tapped only on the east and west side. The first tapping generally takes place on the east side.

We have seen trees which have been tapped continuously for almost fifty years. This can be told by the number of notches. The age of a date tree, which has been tapped regularly, can thus be easily told by adding the number of notches to six years, the age at which, as a rule, tapping first takes place. The average sap-yielding life of a tree, however, is probably not much more than 25 years. Even then, the old tree is still of some considerable value as a fuel and for other purposes.

The yield of sap is greatest in midwinter. The sap collected on calm and cloudless nights gives *gur* of the best quality. Cloudy and foggy nights affect both the quality and quantity of the juice adversely. It is said that in January, when the trees are in full inflorescence, the sap becomes very poor in sugar, though profuse in quantity, and as a rule does not produce good crystals.

Smoking the pots. The earthen pots in which the juice is collected are well smoked every morning as soon as they are emptied. It is noticeable that after smoking the pots are always kept mouth downwards on the ground all day, until they are hung up on the trees again in the afternoon. The smoking is done by putting a number of pots mouth downwards over a heap of rubbish, such as leaves, date leaves or *bhusa* (finely broken straw), and then firing the rubbish. The interior of the pots is thus thoroughly smoked. The treatment is over in a few minutes, and is supposed to help to keep the juice from fermentation.

PART III. WORK IN THE FIELD.

The work will be dealt with under the following heads:—

- A. The improvement of the quality of the juice.
 - (a) Night juice.
 - (b) Day or *ola* juice.
 - (c) The effect of washing the cut surface of the tree on the quality of the juice.
- B. Improvements in the quality of the *gur*.
 - (a) Colour.
 - (b) Sugar content.
- C. Fuel experiments.

A. THE IMPROVEMENT OF THE QUALITY OF THE JUICE.

(a) NIGHT JUICE.

In our previous work it was shown that much sugar was lost by inversion during the night after the juice had left the tree. We suggested that this loss might be partly due to the dirty condition of the earthen pots which are used to collect the juice. We therefore considered that, if metal receptacles were used as a means of collection, a better quality of juice would be obtained. Preliminary experiments had also indicated to us in our former work that, if small amounts of formalin were placed in the collecting pots over-night, the juice would be better preserved.

In Madras the Excise authorities enforce the use of lime cream in pots which are being used to collect juice from the palms for sugar-making. A personal study of the conditions under which this industry is carried on showed that the quality of the juice obtained, and of the jaggery made from it, was of far higher quality than the juice and *gur* in Bengal.

In our previous work we also investigated the effect which the common Bengal practice of smoking the pots has on preserving the juice. The effect was found to be distinctly beneficial. It may be mentioned that it is also a fairly common practice to smoke pots in which milk is to be transported. The reason for this preservative effect of the smoke will be discussed elsewhere.

The following series of experiments were planned to compare the five different means of collecting the juice set out below:—

I. Earthenware pots such as the tappers themselves use, but these pots were not smoked or treated in any way.

II. Earthenware pots such as the tappers use, but the pots were smoked nightly; hence this is exactly the way in which the juice is collected in the date sugar districts.

III. Earthenware pots such as the tappers use, but the inside was daily lightly smeared with lime made up by mixing lime and water to a thick cream.

IV. Earthenware pots containing a small amount of formalin, 50 c.c. of ordinary commercial formalin, *i.e.*, 40 per cent. was diluted to 1000 c.c. Five c.c. of this weak solution was put into each pot. (28 c.c.=1 oz. roughly.)

V. Metal buckets.¹ The buckets used were buckets such as are used in North America for the collection of maple juice, and were obtained from Messrs. Grimm and Co., Vermont. These buckets received no treatment beyond daily washing with water.

Each of the above five series consisted of 8 pots, or in the case of No. V of 8 buckets. Thus there were 40 trees under experiment nightly. Efforts were made to use only trees yielding *jiran* juice.

The pots were attached to the tree in the afternoon in the usual manner and removed next morning at 7 to 8 A.M. Since it was impossible with the staff available to analyse the juice from the 40 individual receptacles each day, the juice of each series was mixed together, and from the five samples thus obtained samples were drawn for analysis. The sucrose and reducing sugar were then determined in each sample.

The experiment was continued almost daily for more than three weeks, so that fairly reliable results were obtained. It should be mentioned that in the first place all the pots used were quite new on the first day of experiment. The four series of earthen pots were plainly marked with distinctive colours, and the pots of each series were used only for their own particular series throughout the experiment.

The only criticism which can be offered of the method of experiment seems to be the fact that we were not dealing with trees all of which gave juice of the same quality.

¹ Investigations at Vermont, U. S. A., show that sap keeps better in metal vessels in U. S. A. (*Jour. Soc. of Chem. Ind.*, May 30th, 1914.)

It would, however, be impossible to select trees of such a uniform character. By including 8 trees nightly in each series, and carrying out the experiments through more than three weeks, as above described, it was hoped that any difference factor due to original difference in composition of the juice of each series would be largely eliminated. The results obtained are so definite that we can readily trace the action of each particular treatment. With a view to finding the kind of difference likely to be due to difference among the trees, on two nights experiments were carried out with series of pots all of which had been untreated. On the 7th February 1916, and 14th February, 1916, five sets of pots, eight in each set but all untreated, were used for juice collection. The results obtained are set out in the table under the dates mentioned. It will be seen that there is considerable variation among the trees themselves, but the ratio of reducing sugars to total sugars shows the juices to be all very bad.

Perhaps a more reliable way of testing the various methods of juice collection is that set out on pages 81 and 82.

All the results obtained in the series of experiments above described are set out in the tables below :—

Date	Method of collection	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar	REMARKS
20-1-16	Untreated pots ..	9.98	
	Do. ..	12.34	0.51	12.85	4.0	
	Do. ..	11.57	1.22	12.79	9.5	
21-1-16	Untreated pots ..	10.10	1.16	11.26	10.3	
	Smoked	11.59	0.74	12.33	6.0	
	Limed	10.02	0.87	10.89	8.0	
	Formalin	10.54	0.95	11.49	8.3	
	Metal buckets ..	10.95	1.64	12.59	13.2	
22-1-16	Untreated pots	Too badly fermented to analyse.
	Smoked pots ..	12.10	0.94	13.04	7.2	
	Limed	11.61	0.91	12.52	7.3	
	Formalin	9.15	2.60	11.75	22.1	
	Metal buckets ..	8.94	2.60	11.54	22.5	
23-1-16	Untreated pots	4.00	Too badly fermented to analyse.
	Smoked pots ..	10.14	1.25	11.35	11.0	
	Limed	10.02	1.88	11.90	15.8	
	Formalin	9.93	2.08	12.01	17.3	
	Metal buckets ..	8.63	2.56	11.19	22.9	

Date	Method of collection	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar	REMARKS
24-1-16	Untreated pots ..	8.21	1.33	9.54	14.0	
	Smoked " ..	10.31	0.85	11.16	7.6	
	Limed " ..	9.82	0.62	10.44	5.9	
	Formalin " ..	10.59	1.11	11.70	9.5	
	Metal buckets ..	10.26	1.61	11.87	13.5	
25-1-16	Untreated pots ..	10.35	0.98	11.33	8.6	
	Smoked " ..	11.17	0.52	11.69	4.5	
	Limed " ..	9.89	1.03	10.92	9.4	
	Formalin " ..	11.11	0.65	11.76	5.5	
	Metal buckets ..	9.69	1.39	11.08	12.5	
26-1-16	Untreated pots ..	11.20	0.76	11.96	6.4	
	Smoked " ..	11.55	0.51	12.06	4.2	
	Limed " ..	11.48	0.75	12.05	4.7	
	Formalin " ..	10.30	0.90	11.20	8.0	
	Metal buckets ..	10.82	1.28	12.10	10.6	
27-1-16	Untreated pots ..	9.90	1.85	11.75	15.7	
	Smoked " ..	11.88	0.53	12.41	4.3	
	Limed " ..	10.34	0.75	11.09	6.8	
	Formalin " ..	10.06	1.33	11.39	11.9	
	Metal buckets ..	10.80	1.69	12.49	13.5	
28-1-16	Untreated pots ..	9.95	1.40	11.35	12.3	
	Smoked " ..	11.87	0.66	12.53	5.2	
	Limed " ..	11.10	0.82	11.92	6.9	
	Formalin " ..	10.58	1.47	12.05	12.2	
	Metal buckets ..	10.00	1.53	11.53	13.3	
29-1-16	Untreated pots ..	10.34	1.39	11.73	11.9	
	Smoked " ..	11.30	0.73	12.03	6.1	
	Limed " ..	11.52	0.76	12.28	6.2	
	Formalin " ..	9.64	1.72	11.36	15.1	
	Metal buckets ..	0.36	1.69	12.05	14.0	
30-1-16	Untreated pots ..	10.03	1.22	11.25	10.9	
	Smoked " ..	11.39	1.07	12.46	8.6	
	Limed " ..	10.16	0.75	10.91	6.9	
	Formalin " ..	9.83	1.88	11.71	16.1	
	Metal buckets ..	10.13	1.02	11.15	9.1	
31-1-16	Untreated pots ..	11.03	1.45	12.48	11.6	
	Smoked " ..	12.42	0.87	13.29	6.5	
	Limed " ..	11.36	0.67	12.03	5.6	
	Formalin " ..	8.96	2.38	11.34	21.0	
	Metal buckets ..	8.21	1.43	9.64	14.8	
1-2-16	Untreated pots ..	10.48	1.47	11.95	12.3	
	Smoked " ..	11.31	1.00	12.31	8.1	
	Limed " ..	11.11	0.76	11.87	6.4	
	Formalin " ..	10.28	2.63	12.91	20.4	
	Metal buckets ..	10.40	1.20	11.60	10.4	

Date	Method of collection	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar	REMARKS
2-2-16	Untreated pots ..	8.96	2.71	11.67	23.2	Warm spell of weather.
	Smoked „ ..	11.63	1.10	12.73	8.6	
	Limed „ ..	10.29	1.47	11.76	12.5	
	Formalin „ ..	9.95	1.45	11.40	12.7	
	Metal buckets ..	10.39	1.11	11.50	9.6	
4-2-16	Untreated pots ..	10.59	1.66	12.25	13.5	
	Smoked „ ..	10.28	1.66	11.94	13.9	
	Limed „ ..	11.50	0.86	12.36	7.0	
	Formalin „ ..	9.13	1.64	10.77	15.2	
	Metal buckets ..	10.47	1.39	11.86	11.7	
5-2-16	Untreated pots ..	7.29	4.00	11.29	35.4	
	Smoked „ ..	9.77	1.14	10.91	10.4	
	Limed „ ..	10.02	1.12	11.14	10.0	
	Formalin „ ..	9.99	1.47	11.46	12.8	
	Metal buckets ..	10.49	1.49	11.98	12.4	
6-2-16	Untreated pots ..	..	..	..	..
	Smoked „ ..	6.77	2.40	9.17	26.2	
	Limed „ ..	..	..	..	..
	Formalin „ ..	9.20	1.74	10.94	16.0	
	Metal buckets ..	10.39	1.26	11.65	10.8	
7-2-16	Untreated pots ..	..	..	..	..
	Smoked „ ..	10.37	1.92	12.29	15.6	
	Limed „ ..	..	..	..	..
	Formalin „ ..	10.00	1.69	11.69	14.5	
	Metal buckets ..	10.43	1.31	11.74	11.2	
8-2-16	Untreated pots ..	..	..	..	..
	Smoked „ ..	12.18	1.53	13.71	11.1	
	Limed „ ..	11.87	0.78	12.65	6.2	
	Formalin „ ..	..	..	..	..
	Metal buckets ..	11.29	1.51	12.80	11.8	
10-2-16	Untreated pots ..	10.58	1.25	11.83	10.6	
	Smoked „ ..	..	..	..	..
	Limed „ ..	9.97	0.54	10.51	5.1	
	Formalin „ ..	..	..	..	..
	Metal buckets ..	11.41	0.87	12.28	7.1	
11-2-16	Untreated pots ..	10.43	2.32	12.75	18.2	
	Smoked „ ..	11.67	1.82	12.49	14.6	
	Limed „ ..	13.58	0.63	14.21	4.4	
	Formalin „ ..	..	..	..	..
	Metal buckets ..	..	..	..	..
12-2-16	Untreated pots ..	12.40	1.53	13.93	11.0	
	Smoked „ ..	11.10	2.56	13.66	19.0	
	Limed „ ..	11.31	0.51	11.82	4.3	
	Formalin „ ..	12.00	1.78	13.78	12.9	
	Metal buckets ..	12.36	1.35	13.71	9.9	

Date	Method of collection	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar	REMARKS
13-2-16	Untreated pots ..	13.46	1.43	14.89	9.6	
	Smoked „ ..	11.02	1.49	11.51	11.9	
	Limed „ ..	12.92	1.03	13.95	7.4	
	Formalin „ ..	11.31	1.51	12.82	11.8	
	Metal buckets ..	12.61	1.66	14.27	11.6	
7-2-16	(a) Untreated pots	10.63	2.00	12.63	15.8	
	(b) do. ..	8.71	3.57	12.28	29.0	
	(c) do. ..	8.14	2.27	10.41	21.8	
	(d) do. ..	10.37	2.27	12.64	18.0	
	(e) do. ..	9.97	2.12	12.09	17.5	
14-2-16	(a) Untreated pots	9.32	2.04	11.36	18.0	
	(b) do. ..	11.96	1.51	13.47	11.2	
	(c) do. ..	9.76	2.27	12.03	18.9	
	(d) do. ..	10.05	2.56	12.61	20.3	
	(e) do. ..	10.39	3.12	13.51	23.1	

The following series of experiments were designed to test more accurately the effect of various methods of collecting the juice. Three to four litres of juice were collected in the evening, well mixed, and analysed. The following five series of tests were then prepared at about 9 P.M.

1. *Untreated pots.* 8 earthenware pots, such as the tappers use, were taken, and 800 c.c. of juice added to each. These pots received no treatment.

2. *Smoked pots.* Exactly as under 1, but each of the pots was smoked by the cultivators in the usual way.

3. *Limed pots.* Exactly as under 1, but lime was put into each pot first.

4. *Formalin pots.* Also like 1, but each pot treated with formalin as on page 77.

5. *Metal buckets.* 800 c.c. of juice put into each of 8 metal buckets.

There were thus 40 receptacles, 8 in each series.

The 40 receptacles were then put in a big galvanized iron tank well off the ground, so that they would not be disturbed by jackals, etc. In the morning about 9 A.M. the juice of each series was collected together, and from the 5 lots of juice so collected a sample was taken for analysis. The temperature of each sample was also taken. This method of experimenting ensured that the juice taken in each series of tests was of the same composition to begin with.

The following table summarizes the results obtained in each of the three nights on which this series was carried out.

14-2-16. About 34,000 c.c. juice collected at 9 P.M. Its analysis is set out below. 800 c.c. was put into each of the 8 pots of each 5 series, *i.e.*, 40 pots in all.

Date	Method of storage	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar	Temperature of mixed juice °C.
14-2-16 9 P.M.	Original juice ..	13.58	1.43	15.01	9.5	18.5
15-2-16 9 A.M.	Untreated pots ..	10.27	4.35	14.62	30.0	22.5
	Smoked „ ..	11.02	3.12	14.14	22.1	21.5
	Limed „ ..	13.61	1.33	14.94	8.9	21.0
	Formalin „ ..	11.16	3.12	14.28	21.9	21.9
	Metal buckets ..	11.88	2.78	14.66	19.0	23.0

15-2-16. About 22,000 c.c. juice was collected at 9 P.M. Its analysis is set out below. 500 c.c. was put into each of the 8 pots of each 5 series exactly as above.

15-2-16 9 P.M.	Original juice ..	12.77	1.69	14.46	11.7	20.5
16-2-16 9 A.M.	Untreated pots ..	8.01	6.66	14.67	45.4	20.6
	Smoked „ ..	9.95	5.00	14.95	33.4	22.3
	Limed „ ..	12.39	1.53	13.92	11.0	21.0
	Formalin „ ..	10.68	3.84	14.52	26.4	21.2
	Metal buckets ..	10.60	3.57	14.17	25.2	21.5

18-2-16. The total volume of juice collected at night was not recorded, but its analysis is set out below. An equal quantity was put into each of 8 pots of each 5 series exactly as above.

18-2-16 9 P.M.	Original juice ..	13.15	1.56	14.71	10.6	15.0
19-2-16 9 A.M.	Untreated pots ..	10.52	3.44	13.96	24.6	18.1
	Smoked „ ..	11.70	2.00	13.70	14.6	18.0
	Limed „ ..	12.23	0.80	13.03	6.1	17.7
	Formalin „ ..	12.11	1.64	13.75	11.9	18.0
	Metal buckets ..	10.47	3.33	13.80	24.1	17.8

The results of these series of experiments are very definite. It is quite obvious that lime keeps the juice almost perfectly.

In the course of other work a certain amount of data was also accumulated, showing the effect of smoking, liming, and formalin treatment on the quality of juice collected.

The work on *ola* juice (that is the juice which falls from the tree during the day time), described on pp. 87-92, shows that liming has a truly wonderful effect. Formalin there also had a marked effect, though it is seen to be much inferior to lime. The untreated *ola* juice, *i.e.*, simply collected in unsmoked pots, will be seen to be practically all useless for sugar production, the ratio of reducing to total sugar frequently being above 50.

It will be convenient to insert here a few analyses showing the effect of the use of lime on *dokat* juice. *Dokat* juice is usually much inferior to *jiran* juice. Lime seems to have a very marked effect in improving its quality. In the following table are also included analyses of *dokat* juice collected by the cultivators in their own way.

Dokat juice.

Date	Treatment	Sp. gr.	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total sugar	
20-2-16	Cultivator's ..	1.046 (27°C.)	9.16	2.27	11.43	19.9
	Limed ..	1.053 (27°C.)	12.45	0.63	13.08	4.8
21-2-16	Cultivator's ..	1.056 (26°C.)	10.64	2.63	13.27	19.8
	Limed ..	1.054 (25°C.)	11.19	0.66	11.85	5.6

Conclusions.

1. *Effect of smoking the pots.* On referring to the tables we must particularly consider the ratio of reducing sugar to total sugar as this is the test by which to judge the results.

The lower the figure expressing the ratio the more beneficial is any particular treatment. As compared with the untreated pots it will be seen that the smoking has an extremely beneficial effect. It seems to give far better results than the use of metal buckets and frequently better than those of formalin.

As compared with lime it would appear on first glancing at the figures on pp. 78-81, that it had given results equally good. As the weather warmed up in February, however, it was seen to be much inferior to lime, and from general observations of many individual juices collected in limed and smoked pots

there is no question as to the inferiority of the smoking process. The results of the experiments set out on pp. 81-82 show clearly that smoking is far inferior to liming, and in those experiments it is rather inferior to the use of formalin or to the method of collecting in metal buckets. There is no doubt that smoke has some preservative effect on the juice and this is being discussed elsewhere.

2. *Effect of liming the pots.* The use of lime in the pots has given very excellent results, and from a consideration of the results on pp. 78-82 is seen to be easily the best method of collection. It preserves the juice in a really wonderful way. Later experiments on the use of lime for preserving the juice gathered during the day and on the good quality of the *gur* made from the limed juice will add further arguments for the adoption of lime treatment in the date sugar districts. The action of lime is worth while explaining. In the juice as ordinarily collected in the gardens are numerous bacteria, yeasts and moulds, all of which destroy the sugar. There are also numerous non-living ferments often secreted by these organisms, which are capable of changing the cane sugar into the less valuable reducing sugars. The use of a preservative such as smoke or formalin will check the development of the living organisms. It will not however prevent the action of a non-living ferment such as invertase which changes cane sugar to the reducing sugar. Lime, however, in addition to being a good sterilizing agent for living organisms, is strongly alkaline. This alkalinity quite prevents the action of the invertase ferment.

In the experiments described on pp. 81-83, it will be seen that the juice treated with lime would appear to have been actually improved in quality by the destruction of reducing sugar. Thus in the experiments of 18-19 February, 1916, the reducing sugar in the original juice was 1.56 per cent.; after storage with lime it was 0.80 per cent. only. The other two experiments show similar but smaller reductions in reducing sugar content after lime treatment. It has been shown by other workers that lime destroys reducing sugar. In our work we have repeatedly observed the disappearance of reducing sugar from juices stored with lime.

3. *Effect of formalin.* In our previous memoir (pp. 386-388) were described some experiments in which formalin was used in the collecting pots as a means of preserving the juice. These experiments were favourable to the use of this substance, but it is to be noted that the formalin used was 10 per cent. in strength.

In the series of experiments described in this paper only 2 per cent. formalin was used (see p. 77).

In the tables on pp. 78-81, it will be seen that formalin has had very little effect. In fact frequently formalin juices were the worst of the series. In the more reliable experiments whose results are tabulated on p. 82, formalin treatment shows a distinct superiority over the smoking treatment. The action of formalin appeared to us to be uncertain. At times it gave excellent results, whilst at other times it seemed actually to hasten the deterioration of the juice.

We must conclude that in the strengths in which we used formalin during the past season it is of very little use. Perhaps in greater amounts it might be worth while using.

4. *Effect of metal buckets.* These unexpectedly gave very disappointing results. More often than not the juice collected in buckets was the worst of the series.

Some preliminary experiments early in the season indicated that the use of the buckets would be very advantageous as the juice collected in them contained over 12 per cent. sucrose and less than $\frac{1}{2}$ per cent. of reducing sugars. In view of the later results, however, it would seem the good quality of juice in these early experiments must be ascribed to the good quality of the juice collected early in the season.

The poor results obtained with buckets were quite unexpected. The most obvious reason which suggests itself in explanation of the poor results is that the porous pots, owing to evaporation from their outer surface, keep the juice much colder than do metal buckets. This would tend to allow less inversion of cane sugar. Since it was anticipated that the juice collected in buckets might be warmer than that collected in pots, the temperature of the juice in each pot of each series was taken on many occasions at the time of its collection in the morning.

There is no regular higher temperature to be noted in the buckets as compared with the earthen pots. The differences as a rule are negligible. Sometimes higher temperatures were obtained in the pots. Thus on the 26th January, 1916, the temperature of the juice in each of the eight smoked pots was 13.0, 13.0, 15.5, 13.2, 14.4, 13.6, 13.8, and 14.4, an average of 13.8°C. The temperature in each of the buckets was 13.0, 12.8, 14.1, 12.0, 13.0, 14.0, 12.8, and 14.4, an average of 12.8°C. Yet reference to the table on page 79 for the same date will show that the ratio of reducing to total sugars is much higher in the case of the metal buckets than in that of the earthen pots, viz., 10.6 as against 4.2. It would seem that there is some other reason for the inferiority of the buckets to earthen pots.

It was perfectly obvious in the course of the experiments that liming was giving excellent results. It was decided, however, to make a few experiments using a larger quantity of lime to see if even better results could be obtained. Gibbs and Pratt¹ in their work on Nipa palms in the Philippine Islands state that they have found an oxidizing enzyme present in the juice which had the power of destroying the cane sugar. They found that a small amount of sodium sulphite added to the lime gave even better results than lime alone, presumably because the oxidizing enzyme was destroyed by the sulphite. It was decided to include in the set of experiments now to be described a test to see if the addition of sulphite to the lime gave better results than lime alone. In the experiment headed "sulphited lime" the lime used had had some sulphur-dioxide gas bubbled through it for some time.

There were thus three series of pots:—

Ordinary amount of lime	8 pots.
Highly limed	8 "
Highly limed and sulphited	8 "

Twenty-four trees yielding *jiran* juice were taken for the experiments, and one pot was attached to each tree on the evening of the 17th February, 1916. The next morning the juice of each series was mixed together into one lot, and a sample of each of the three lots was drawn for analysis. The results for the two evenings on which the work was carried out are set out below:—

Date of analysis	Manner of preservation	Sucrose gm. per 100 c.c.	Reducing sugar gm. per 100 c.c.	Total sugar gm. per 100 c.c.	Ratio reducing sugar to total sugar
17/18-2-16	Limed	10.55	0.68	11.23	6.1
	Heavily limed	9.29	0.30	9.59	3.1
	Heavily limed and sulphited	9.93	0.24	10.17	2.4
19/20-2-16	Limed	11.72	0.66	12.38	5.3
	Heavily limed	11.75	0.43	12.18	3.5
	Heavily limed and sulphited	11.90	0.57	12.47	4.6

These tests indicate that in the previous experiments with lime we were not using a sufficient quantity of that substance. In each case the heavily limed pots have given a better juice than the pots in which lime was used in a smaller quantity as measured by the ratio reducing sugar to total sugar.

¹ *Phil. Jour. of Sci.*, Series A, 1913, p. 383.

The presence of sulphite in the lime does not seem to have had any beneficial effect.

Recommendation.

The practice of liming the pots should be introduced into palm-sugar-making districts of Bengal. The amount of lime required is so small that its cost would be almost negligible.

(b) "OLA" OR DAY JUICE.

The juice used for sugar production is solely collected at night. During the day juice still continues to flow from the cut surface of the tree. Occasionally this is collected and in the evening boiled down. It is so badly fermented, however, that good *gur* is never obtained from it. The treacle obtained is commonly mixed with the good sample of *gur* obtained next morning. Because of its poor quality by far the largest portion of this day or *ola* juice is not collected at all but simply runs to waste.

It may be pointed out that in Madras the day juice as well as the night juice is used for the production of sugar. It would therefore apparently help the Bengal industry if the day juice could be utilized for sugar production.

A number of measurements have been made of the amount of juice flowing from various trees in the day time. These are recorded in the following table:—

Date	Number of trees measured	Total weight of juice in lb.	Average weight of juice per tree in lb.
6-2-16	34	53.7	1.60
7-2-16	7	11.2	1.60
8-2-16	33	48.2	1.50
9-2-16	34	52.0	1.50
11-2-16	8	9.5	1.20
12-2-16	8	9.8	1.20
13-2-16	33	66.0	2.00
14-2-16	8	3.5	0.40
15-2-16	33	55.4	1.70
16-2-16	6	7.0	1.20
17-2-16	6	6.2	1.00
TOTAL ..	210	322.5	1.54

It will be seen that a large number of trees have been measured, and the average weight of juice flowing from them each in the day time in early February is more than 1½lb. One tree in one day gave 4½lb., but of course this is an exceptional amount.

In order to show the proportion of the juice flowing from the same tree during the night and during the day the following figures are given :—

Date	Number of trees measured	TOTAL WEIGHT OF JUICE IN LB.		AVERAGE WEIGHT OF JUICE (IN LB.) PERTREE	
		Night juice	Day or <i>ola</i> juice	Night juice	Day or <i>ola</i> juice
11-2-16	8	53.0	9.5	6.6	1.20
12-2-16	8	44.7	9.8	5.6	1.20
13-2-16	8	48.4	11.9	6.0	1.50
14-2-16	8	49.9	3.5	6.2	0.40
15-2-16	8	47.3	10.8	5.9	1.30
16-2-16	6	25.7	7.0	4.3	1.20
TOTAL ..	46	269.0	52.5	5.8	1.14

The table indicates that if the day juice flowing from the tree could also be used for sugar production the out-turn per tree would be increased by $\frac{52.5 \times 100}{269}$ or almost 20 per cent. At present the majority of the day juice runs to waste, the cultivators collecting day juice only from those trees which yield considerable quantities. Taking the Bengal production of palm sugar as 100,000 tons annually, the loss through non-collection of the day juice amounts to about 20,000 tons annually.

Another point in favour of collecting this day juice is that it is considerably richer in sugar than is the night juice. In the previous memoir on palm sugar one of us showed that the amount of sugar in the juice tended to increase when the volume of juice decreased and *vice versa*.

We have a large mass of evidence showing that the day juice is richer in sugar than the night juice, but the following few results will illustrate the point :—

Date	SPECIFIC GRAVITY		TOTAL SUGAR IN JUICE GM. PER 100 C.C.	
	Night juice	Day juice	Night juice	Day juice
9-2-16	1.055 (13.5°C.)	1.063 (18°C.)	12.63	14.00
11-2-16	1.055 (20°C.)	1.061 (22°C.)	12.96	14.07
12-2-16	1.056 (14°C.)	1.065 (18°C.)	12.36	14.52
13-2-16	1.054 (21°C.)	1.063 (23°C.)	12.40	13.82
14-2-16	1.055 (11°C.)	1.072 (23°C.)	12.92	15.55
15-2-16	1.055 (23°C.)	1.063 (24°C.)	13.00	14.71

It is therefore plain that by collecting all the day juice we should not only increase our yield of juice by 20 per cent., but the juice obtained would contain from 10 to 20 per cent. more sugar.

It has already been pointed out that the reason why so much of the day juice runs to waste is because it is so badly fermented that a crystalline solid *gur* cannot be obtained from it. On concentration it gives simply a liquid mass of molasses.

A series of experiments were therefore started to see if it were possible to improve the quality of the day juice. In the first place the effect of formalin in preserving the juice was tried.

Sixteen new earthen pots such as the cultivators use for juice collection were taken. On the morning of the 22nd January, 1916, eight of these pots had 5 c.c. of a dilute formalin solution (50 c.c. of commercial formalin diluted to 1000 c.c.) added to each. The remaining eight pots received no treatment. All the 16 pots were then put in position on 16 different trees for juice collection. In the evening the juice from the untreated pots was collected into one sample and the juice from the formalin series into another sample. A sample of each juice was drawn for analysis. The experiment was carried out for some days with the results set out in the following table:—

Date	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total	
22-1-16	Untreated ..	1.050	8.57	Not analysed. 3.22		27.2
	Formalin ..					
23-1-16	Untreated ..	....	5.69	3.84	9.53	40.3
	Formalin ..		9.50	3.57	13.07	27.3
24-1-16	Untreated ..	1.052 (24°C.)	6.36	5.55	11.91	50.9
	Formalin ..	1.045 (24°C.)	7.33	2.86	10.19	28.0
25-1-16	Untreated ..	1.053 (25°C.)	10.97	Not analysed. 4.54		29.3
	Formalin ..	1.059 (24.5°C.)				
27-1-16	Untreated ..	1.049 (27.5°C.)	5.97	4.34	10.31	42.1
	Formalin ..	1.053 (27°C.)	10.06	2.50	12.56	19.9
28-1-16	Untreated ..	1.054 (26°C.)	5.01	5.88	10.89	54.0
	Formalin ..	1.057 (26°C.)	10.47	2.94	13.41	22.0
29-1-16	Formalin ..	....	11.49	2.12	13.61	15.6
31-1-16	Formalin ..	....	7.36	4.54	11.90	38.0
1-2-16	Formalin ..	....	6.93	4.17	11.10	27.0
2-2-16	Formalin ..	....	6.84	5.88	12.72	46.2

These experiments show that by the use of quite small amounts of formalin the quality of the day or *ola* juice can be considerably improved. At the same time there is room for greater improvement. We frequently collected the day juice in limed pots and always obtained extraordinarily good results.

A series of experiments was therefore put up to test the comparative merits of the liming and formalin treatments. The liming was carried out by smearing the inside of the pots with lime cream. The formalin treatment was carried out as in the previous series of experiments. Eight trees were selected for the experiments and the cut surface of each so modified that two bamboo collecting spouts could be inserted into each. In this way two pots could be attached to each tree. The idea of this procedure was that probably the juice flowing into each of the two pots could be of the same composition. A few experiments made to test this point showed that the juice flowing from different portions of the same cut surface was liable to considerable variation in composition. The experiments, however, are all given for what they are worth. In the table on each day is also recorded the analysis of some *ola* juice collected by the cultivator in his ordinary way. This is called untreated.

Date	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total sugar	
5-2-16	Formalin ..	1.047 (23.5°C.)	6.94	3.82	10.76	35.5
	Limed ..	1.047 (23.5°C.)	8.57	1.95	10.52	18.5
	Untreated ..	1.039 (26°C.)	..	7.41	..	..
6-2-16	Formalin ..	1.057 (24°C.)	10.95	2.35	13.30	17.7
	Limed ..	1.061 (24.5°C.)	11.65	1.88	13.53	13.9
	Untreated ..	1.051 (26°C.)	small	9.51	..	..
7-2-16	Formalin ..	1.062 (25.5°C.)	13.86	2.09	15.95	13.1
	Limed ..	1.065 (25.5°C.)	13.95	0.99	14.94	6.6
	Untreated ..	1.056 (26°C.)	small	10.51	..	..
8-2-16	Formalin ..	1.063 (16.5°C.)	13.12	0.99	14.11	7.0
	Limed ..	1.062 (17°C.)	12.80	0.66	13.46	4.9
	Untreated ..	1.052 (15°C.)	9.06	2.06	11.12	18.5
9-2-16	Formalin ..	1.064 (19°C.)	13.47	0.80	14.27	5.6
	Limed ..	1.062 (17°C.)	12.67	0.58	13.25	4.4
	Untreated ..	1.062 (18°C.)	10.55	2.29	12.84	17.8

Date	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total sugar	
11-2-16	Formalin ..	1.061 (22°C.)	12.60	1.49	14.90	10.6
	Limed ..	1.061 (22°C.)	12.75	1.29	14.04	9.2 *
	Untreated ..	1.061 (22°C.)	5.89	6.69	12.58	53.2
12-2-16	Formalin ..	1.064 (18°C.)	12.32	2.13	14.45	14.8
	Limed ..	1.065 (18°C.)	13.32	1.26	14.58	8.6
	Untreated ..	1.077 (17°C.)	10.06	7.15	17.21	41.6
13-2-16	Formalin ..	1.062 (22°C.)	12.12	1.67	13.79	12.0
	Limed ..	1.063 (23°C.)	12.57	1.27	13.84	9.2
	Untreated ..	1.062 (22°C.)	8.08	5.22	13.31	39.2
14-2-16	Formalin ..	1.072 (23°C.)	13.28	2.82	16.10	17.5
	Limed ..	1.072 (23°C.)	13.28	1.72	15.00	11.5
	Untreated ..	1.053 (24°C.)	4.60	7.31	11.91	61.4
15-2-16	Formalin ..	1.062 (24°C.)	12.93	1.80	14.73	12.8
	Limed ..	1.065 (24°C.)	13.55	1.15	14.70	7.8
	Untreated ..	....	..	..	..	..
16-2-16	Formalin ..	1.067 (23°C.)	12.35	2.34	15.69	21.3
	Limed ..	1.061 (24°C.)	10.46	2.35	12.81	18.3
	Untreated ..	....	..	..	..	..
17-2-16	Formalin ..	1.062 (19°C.)	12.51	..	..	..
	Limed ..	1.059 (19°C.)	12.90	0.96	13.86	6.9
	Untreated ..	..	..	..	..	..

* No more lime added through oversight.

A study of the ratio reducing sugar to total sugar in the last column shows the extremely bad quality of the untreated juice. It also shows that liming is much superior to formalin as a means of improving the quality of the *ola* juice.

A few other odd analyses are here appended of *ola* juice which was collected in limed pots.

Date	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total sugar	
30-1-16	Limed ..	1.055 (23.5°C.)	10.72	1.29	12.01	10.7
31-1-16	Limed ..	1.050 (21.5°C.)	9.11	2.32	11.43	20.3
2-2-16	Limed ..	1.054 (24°C.)	9.64	2.79	12.43	22.4
10-2-16	Limed ..	1.055 (23°C.)	12.25	0.67	12.92	5.2
18-2-16	Limed ..	1.060 (21°C.)	11.83	0.60	12.43	4.8

We made a number of attempts to make *gur* from *ola* or day juice. These always succeeded in the case where the juice had been collected in limed pots.

We obtained a good crystalline *gur* much to the astonishment of the tappers who had never seen good *gur* made from *ola* juice before.

Our attempts to make *gur* from ordinary untreated *ola* juice always failed. From formalin treatment of *ola* juice we frequently got excellent *gur*, but on a number of occasions we met with failures.

Ola juice which has been limed need not be boiled into *gur* at once. This is fortunate as otherwise the cultivator in order to make *gur* from *ola* juice would have to make two boilings per day. The juice can safely be kept till next morning without deterioration and can then be mixed with the juice collected at nights. The following table shows the analysis of three *ola* juices collected in lime-treated pots. The juices were kept till next day, a period about 17 hours, and again analysed. It will be seen there was practically no deterioration of the quality of the juice in any case.

Juice	Date	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
			Sucrose	Reducing sugar	Total sugar	
No. 1	16-2-16	1.061 (24°C.)	12.00	1.88	13.88	13
	17-2-16	1.061 (26°C.)	12.03	1.74	13.77	13
No. 2	17-2-16	1.054 (19.5°C.)	10.41	1.66	12.07	14
	18-2-16	1.053 (24°C.)	10.44	1.63	12.07	13
No. 3	19-2-16	.....	12.05	0.46	12.51	4
	20-2-16	1.058 (22°C.)	12.11	0.48	12.59	4

Recommendation.

The work under this head points to the quite definite conclusion that, if the practice of liming the pots be introduced, a considerable increase, probably of the order of 20 per cent. of *gur* outturn, could be obtained, because it would be possible to use the day juice for *gur*-making.

(c) EFFECT OF WASHING THE CUT SURFACE OF THE TREE ON THE QUALITY OF THE JUICE.

We have shown that liming the pots is the best means of preserving the juice. A number of experiments were carried out with the idea of finding out how long juice would keep good in limed pots. We have found that if sufficient lime be used the juice may be kept with loss of sucrose for many weeks. The reducing sugars practically disappear. In the case of juices which had been stored with an insufficiency of lime we obtained a peculiar gum fermentation. The sucrose completely disappeared, being replaced by a

dextro-rotatory gum, leaving the rotation of the solution almost the same as before fermentation. Much acetic and some formic acid were produced and there was a vigorous evolution of gases. The enquiry into the nature of this fermentation was discontinued on the deputation of the senior author to the United Provinces. When special precautions have been taken to clean carefully the cut surface, juices have been obtained which contained practically no sugar except cane sugar. Such a juice is of course very desirable. The juices actually obtained in practice however contain an appreciable amount of the other and less desirable sugars—glucose and lævulose. Since the limed juices also contain these other sugars, it would seem probable that the juice deteriorates before it reaches the collecting pots perhaps owing to the dirtiness of the cut surface and spouts. It was therefore considered of interest to try the effect of washing the cut surfaces and spouts of some trees and to compare the juice obtained with that of juice from unwashed trees. The trees to be washed were first brushed with a brush made from a palm leaf stalk as usually carried by the cultivator and the surface then washed with water. The table sets out the results obtained.

No. of trees	Date	Kind of juice	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
					Sucrose	Reducing sugar	Total sugar	
18	6-2-16	<i>Ola</i>	Limed pots, surface not washed ..	1.051 (23°C.)	6.47	4.13	10.60	39.0
15	"	"	Limed pots, surface washed..	1.053 (23°C.)	11.37	1.33	12.76	10.5
18	7-2-16	"	Limed pots, surface not washed ..	1.057 (25°C.)	12.38	1.12	13.50	8.3
5	"	"	Limed pots, surface washed..	1.065 (25.5°C.)	13.95	0.99	14.94	6.6
22	8-2-16	"	Limed pots, surface not washed ..	1.056 (17°C.)	11.67	0.84	12.51	6.7
5	"	"	Limed pots, surface washed..	1.062 (17°C.)	12.80	0.66	13.46	4.9
25	9-2-16	"	Limed pots, surface not washed ..	1.055 (17°C.)	11.19	1.05	12.24	8.6
9	"	"	Limed pots, surface washed..	1.062 (17°C.)	12.67	0.58	13.25	4.4

No. of trees	Date	Kind of juice	Treatment	Specific gravity	GM. PER 100 C.C.			Ratio reducing sugar to total sugar
					Sucrose	Reducing sugar	Total sugar	
25	13-2-16	<i>Ola</i>	Limed pots, surface not washed ..	1.061 (22°C.)	11.90	1.62	13.52	12.0
8	"	"	Limed pots, surface washed..	1.063 (23°C.)	12.57	1.27	13.84	9.2
25	14-2-16	"	Limed pots, surface not washed ..	1.055 (24°C.)	8.19	3.51	11.70	30.0
8	"	"	Limed pots, surface washed..	1.027 (23°C.)	13.28	1.72	15.00	11.5
25	15-2-16	"	Limed pots, surface not washed ...	1.055 (24°C.)	8.22	4.52	12.74	35.5
8	"	"	Limed pots, surface washed..	1.065 (24°C.)	13.55	1.15	14.70	7.8
	17-2-16	<i>Dokat</i>	Smoked pots, surface not washed ..	1.052 (25°C.)	6.28	7.91	14.19	55.7
			Smoked pots, surface washed	1.052 (26°C.)	8.36	3.80	12.16	31.2
	18-2-16	"	Smoked pots, surface not washed ..	1.048 (18°C.)	8.62	1.98	10.60	18.7
			Smoked pots, surface washed	1.048 (17°C.)	8.60	2.07	10.67	19.4
	20-2-16	"	Limed pots, surface not washed	1.056 (26.5°C.)	12.22	1.52	13.74	11.1
			Limed pots, surface washed..	1.053 (27°C.)	12.45	0.63	13.08	4.8
	21-2-16	"	Limed pots, surface washed	1.059 (25°C.)	12.48	1.31	13.79	9.5
			Limed pots, surface washed..	1.059 (25°C.)	11.19	0.66	11.85	5.6

It will thus be seen that the cleaning of the cut surface has had a distinctly beneficial effect in the case of *ola* and *dokat* juice. With *jiran* juice our experience was that the effect was not so marked, but the results have not been recorded here. The tappers raised the objection that much time would be required to clean the trees. This is not so, however,

since one tapper cut, cleaned, and washed 20 trees before us in 80 minutes. The time also included the attaching of the pots.

Recommendation.

We would therefore recommend that the tappers be encouraged to clean the cut surfaces with water daily especially for *dokat*, *tekat*, and *ola* juice. It is possible that the substitution of dilute formalin for water would give better results.

B. IMPROVEMENTS IN THE QUALITY OF *GUR*.

(a) COLOUR.

Anyone acquainted with the cane and palm sugar industries in India cannot help being struck by the great difference in colour between palm *gur* and cane *gur*. The palm product is very dark, at times almost approaching black in colour. The palm sugar molasses obtained in refining is moreover much darker than the corresponding product from sugarcane. There is no doubt that the dark colour renders palm *gur* unattractive and is one of the reasons why its price is so much lower than that of the cane *gur*.

It has been thought by some that improvement in colour would be obtained by boiling the juice in iron pans instead of earthen pans as is the common practice. Thus Mr. B. C. Basu¹ stated that he prepared *gur* of exceedingly fine quality in iron pans. Mr. H. D. Chatterjee prepared some date palm *gur* in iron pans in Central India and submitted samples to the senior writer. These were brighter in colour than the Bengal palm *gur*, but still they had a characteristic dark colour.

Our own early experience led us to the belief that much sugar was burnt when the earthen pots are used for boiling and that the caramel so formed was a contributory cause to the production of the dark colour.

During the past cold weather we have had much personal experience in the field in making palm *gur* by different methods. The result was that we definitely established the fact that iron or tinned pans though giving a brighter coloured *gur* than the earthen pans yet still produced *gur* with the characteristic dark colour.

The juice itself is normally water white though occasionally some samples have a very faint tinge of brown. Hence the colour of *gur* is not due to a pigment occurring in the juice.

¹ Reports of Department of Land Records and Agriculture, Bengal, 1892-3, pp. 32-33, and 1893-4, pp. 16-17.

Date palm juice, however, is commonly strongly alkaline to litmus when fresh. It is well known that when alkalis are boiled with such sugars as glucose and lævulose black-coloured decomposition products are formed.

Hence it occurred to us that the dark colour of palm *gur* was probably due to the action of the boiling alkaline juice on the reducing sugars contained in it.

We therefore tried the effect of slightly acidifying the palm juice before boiling it. The first experiment was done on a very large scale. 800lb. of juice were taken and put into the boiling pan by the aid of buckets. The juice in each bucket was made just acid in the cold to litmus paper with citric acid. The boiling was then proceeded with. It was soon observed that the liquid was not undergoing the usual darkening. After the furnace had been lighted $1\frac{1}{4}$ hours, a sample of the syrup was withdrawn. It had a very faint pale golden colour with no sign of darkening whatever. Its specific gravity was 1.115 at 15°C. Ordinary juice when boiled to this density is always brown. Three-quarters of an hour later the density of the syrup was 1.165 at 35°C. and it still only had a pale golden colour.

A local sugar-boiler in our employ—a very aged and experienced man—had difficulty in telling when the boiling was finished, since he had never seen a finished syrup of such a light colour. We however constantly took the temperature of the boiling liquid during *gur*-making and we were thus able generally to tell when the boiling was finished. Our final temperature was usually 242–246°F. (116–119°C.)

The *gur* obtained was of an exceedingly light colour equalling the best quality cane *gur*.

After this success we tried many boilings of juice which we had previously acidified by means of various acids. We used sulphuric acid, hydrochloric acid, alum, extract of tamarind fruits, juice squeezed from fresh limes, and the acid liquid left after the souring of milk and the removal of the curd in the native fashion. In all these cases we were able to obtain light-coloured syrups. Hydrochloric acid did not give such good results as the other substances. Hydrochloric acid on boiling with lævulose produces a red colour, and the unsatisfactory results with the acid may have been due to this cause. There was no doubt, however, that the characteristic darkening of ordinary date *gur* was not produced.

Of the above substances perhaps the watery extract of tamarind fruits is the cheapest. Alum is perhaps the most convenient and gives as good

results as anything. For the preparation of a certain light-coloured sweet-meat locally called *patali*, alum and milk are added to the juice before boiling. In the presence of milk a good thick solid scum rises to the surface of the boiling juice and so impurities are more perfectly removed.

The amount of acid substance added to the juice should be such that cold juice rendered neutral to litmus paper with acid becomes just alkaline again on boiling. It requires some experience to hit this point accurately. If too much acid be added then the cane sugar is inverted, that is, changed into the less desirable sugars, glucose and lævulose, and the *gur* obtained will be of a correspondingly poorer quality. Further the juice when made acid very rapidly deteriorates by fermentation.

(b) SUGAR CONTENT.

It has been shown that the practice of liming the pots previous to collection of the juice results in the production of a better quality of juice. The *gur* made from the juice is similarly of a better quality.

Some ordinary *gur* and also *gur* made from limed juice was refined by means of centrifugals at the Tarpur sugar-works. We are indebted to Mr. N. Dutt, the manager, for the loan of centrifugals for this work. The following figures show the results obtained :—

Kind of <i>gur</i>	Weight of <i>gur</i>	Weight of sugar produced	% of sugar to <i>gur</i>
Untreated	2 mds. 17 seers	31 seers	31.0
Limed	1 " 0 "	23½ "	58.7

In the ordinary country process¹ of refining date palm *gur* the yield of sugar obtained represents 40 per cent. of the *gur* taken, 28 per cent. being obtained in one process and the remaining 12 per cent. only being obtained by re-boiling the molasses from the first process to a second *gur* and refining this. In our figures for the *gur* refined by centrifugals as above, the sugar yield would have been increased if we had re-boiled the molasses. It will be seen that the limed *gur* gave an astonishingly large return of sugar (58.7 per cent.) whereas ordinary *gur* gave only 32 per cent. We do not think that such an extraordinarily favourable result would always be obtained, but it is very suggestive. The sugar made was much praised by local refiners who moreover seemed

¹ See page 362, "The Date Sugar Industry in Bengal," *Mem. Dept. Agric., India, Chem. Series*, vol. II, no. 6.

rather surprised that we were able to make such a good quality sugar by means of centrifugals.¹

The native refining industry has already been described fully in our previous memoir and full details given of the cost of each operation and the returns for three different factories over a period of three years. More figures have been collected but these only bear out the previous ones. We have the following objections to this process :

1. Large stocks of *gur* have to be kept. This means the locking up of much capital, and also it is probable that the quality of the *gur* deteriorates on storage.

2. It takes several weeks for each lot of *gur* to pass through the refining process. In this time an appreciable amount of sugar gets lost by fermentation. This is especially the case at the end of the refining season when the weather is warming up. It is then a common sight to see sugar fermenting during the refining process. The process has the advantage that it is cheap since there is very little outlay on apparatus.

We asked why centrifugals had never been tried but were informed that they had been and that sugar could not be obtained from date *gur* by their use. We carried out the centrifugal tests described above. These were in every way successful.

Recommendation.

We are fully of opinion that a thorough trial should be given to centrifugals for refining purposes. The refining industry is large enough to warrant their use on a rather large scale.

C. FUEL EXPERIMENTS.

It has frequently been stated that fuel is becoming more and more scarce in the date sugar districts and that this shortage is tending to curtail the sugar output.

The question of the supply of the fuel for the important palm sugar industry in Burma has also been considered by the authorities there. Mr. McKerral² suggests the centralization of the *gur*-making operation with the idea of economizing the fuel.

It would therefore be of importance to see if some economy in fuel consumption were not possible. To this end a number of experiments

¹ We have been told that in the season 1916-17 centrifugals have been used at one refinery at Kotechandpur and with excellent results.

² Bulletin No. 3, 1910, Department of Agriculture, Burma.

have been carried out with the furnaces as used by the cultivators to determine the amount of fuel used in producing one maund of *gur*.

We think the experiments show that considerable economy of fuel could be effected.

The fuel in common use in the date sugar districts is wood and the dried palm leaves. We have never seen coal in use by the people. In the description of the tapping process on page 72, it will be seen that in preparing the trees a large number of leaves are stripped off. These are all kept and are largely used as fuel. In fact they are almost the sole fuel in use until the middle or end of December. *Rahar* or *arhar* (*Cajanus indicus*) stalks and the wood left after the retting of jute are occasionally used. Thus the growth of such crops as *rahar* and jute helps to solve the fuel problem. *Rahar* can be grown quite conveniently in the date sugar plantations.

The preliminary steps in our fuel enquiry were therefore directed towards investigating the actual amount of date palm leaves or wood used by the cultivator in the production of a maund of *gur*. We then had to find what was a fair value to put upon the wood. In this we had much difficulty. Enquiries among tappers as to the value of fuel used in the production of *gur* showed that they estimated the expenditure in fuel at from 11 annas to 21 annas per maund (82lb.) of *gur* made.

The experiment detailed below points to the fact that about $6\frac{1}{2}$ to 10 maunds of wood are normally used by the cultivators in the production of 1 maund *gur*.

Wood seems to sell at Kotechandpur at about R. 1-5 per cart-load delivered. It has to be dried before use, and hence loses a good deal of weight. The wood costs 6 annas per cart-load for splitting. We actually weighed a number of cart-loads being sold in the market at Kotechandpur, and the table shows the cost per maund of undried wood.

Weight per cart-load	Price per cart-load	Price per cart-load including charge for splitting	Price per md. (82lb.) unsplit wood	Price per md. (82lb.) split wood
lb.	R. A. P.	R. A. P.	R. A. P.	R. A. P.
559	1 5 0	1 11 0	0 3 0	0 3 10
469	1 5 0	1 11 0	0 3 7	0 4 7
473	1 5 0	1 11 0	0 3 5	0 4 5
684	1 5 0	1 11 0	0 2 6	0 3 2
504	1 4 0	1 10 0	0 3 2	0 4 1
398	0 13 0	1 3 0	0 2 7	0 3 10

The average price per maund of split wood therefore works out at 4 annas, and for unsplit at rather over 3 annas. At the same time it must be remembered that the wood dries considerably before use and these prices would have to be increased in consequence. The tapper in Jessore, however, does not admit that this wood costs him as much as the above figures would make out. In the first place he points out that the splitting is done by his own family and he does not have to pay for it. Further they say that they collect their wood before the beginning of the cold weather and it is then much cheaper. They would put the cost of their wood at not more than 2 annas per maund and perhaps less. We do not think there are many places in Bengal where 2 annas a maund would be a fair rate to put on wood.

Enquiries in Goalundo Subdivision of the Faridpur District in March, 1916, elicited the information that wood costs there Rs. 3 per cart-load of 13 maunds of 60lb. each, splitting costs 8 annas per cart-load, so that the price per *pucca* maund of 82lb. works out at 5 annas 7 pies. Coal apparently costs there very little more than wood.

We carried out fuel tests in various kinds of furnaces :—

1. *The ordinary country furnaces.* These invariably consist of holes in the ground over which the earthen boiling pots are supported (*see* Plate VII of our previous memoir). The cultivators commonly have 2 or 4 boiling pots on one furnace. Sometimes only one boiling pot is used. We have seen as many as 16 boiling pans on one furnace. The tests here described were carried out on furnaces carrying one, two, and four boiling pans, and were mostly done at tappers' furnaces, the man carrying out his work in the usual way. We, however, weighed the palm juice used and the *gur* produced, and also the amount of fuel he actually used, and kept a record of time consumed in the making of the *gur*. We also had a furnace of our own erected exactly on the native plan. Tests with this are also included in the tables.

2. *A modified country furnace.* This was a furnace we designed ourselves. We were concerned to alter the native process as little as possible. We used earthen pans to boil the juice in, but we deepened the furnace somewhat and put in iron bars half way down to burn the fuel on so that there should be an underdraught. We also attached a chimney made from kerosene tins to the furnace. The furnace as finally adopted took two boiling pots side by side. We originally tried to have three pots, one behind the other in series, but we could not get good results in this way. With the furnace as finally adopted we had very efficient draught and we obtained good results.

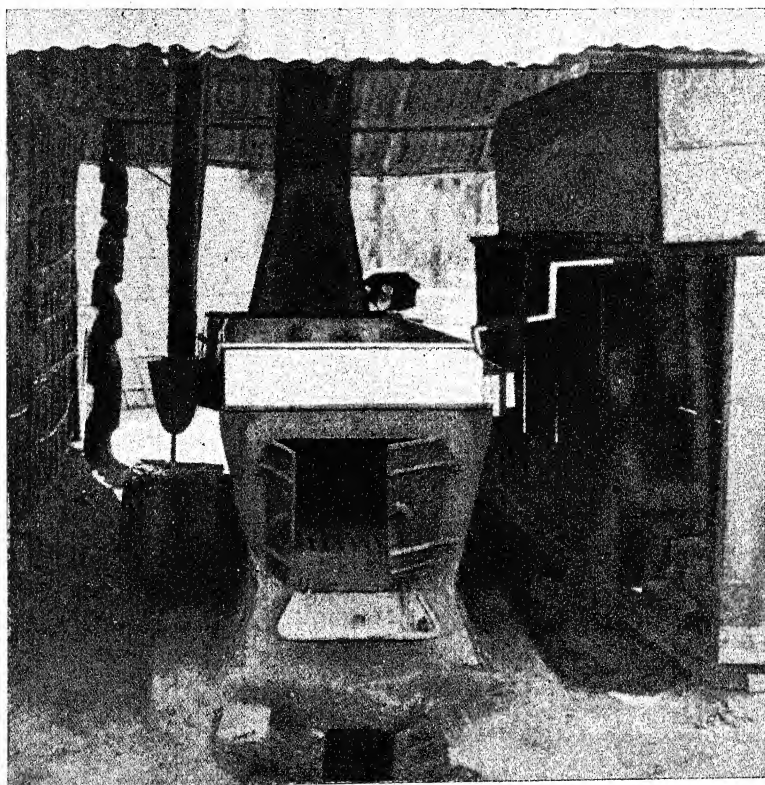


Fig. 1. THE MAPLE SUGAR OUTFIT, SHOWING EVAPORATOR.

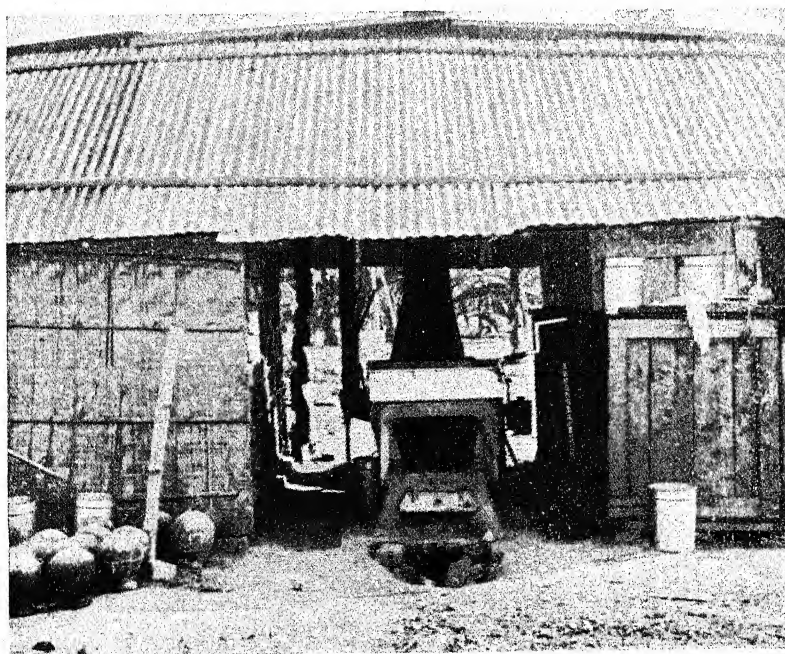


Fig. 2. THE MAPLE SUGAR OUTFIT.

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Fig. 1. THE MAPLE SUGAR OUTFIT, SHOWING SUGARING ARCH.

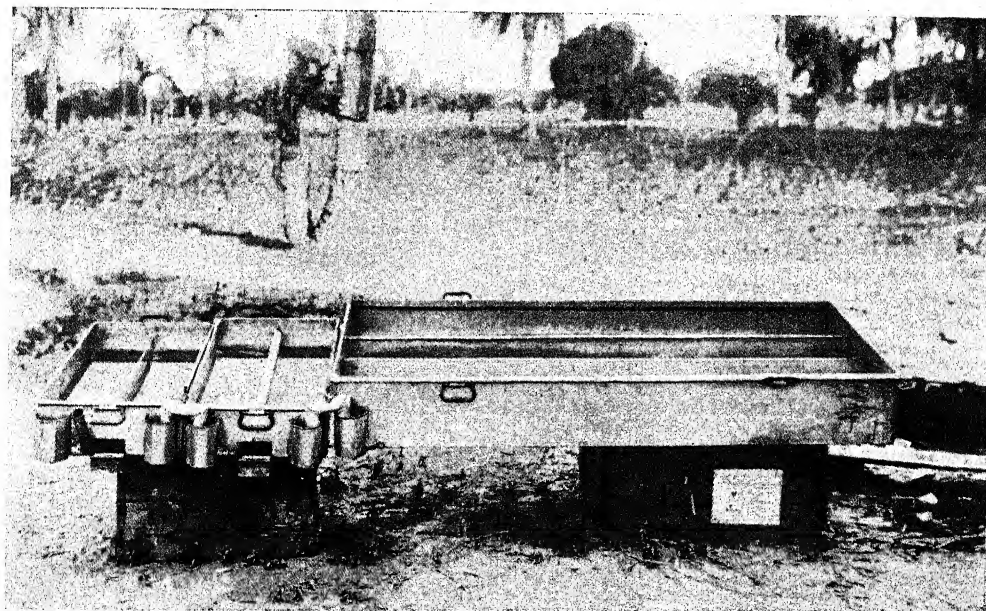


Fig. 2. THE MAPLE SUGAR OUTFIT—EVAPORATOR PORTION.

3. *Iron pan.* A shallow iron pan fitted over a furnace just like the tapper's furnace but much bigger in order to accommodate the iron pan. To this furnace we also attached a kerosene-tin chimney.

4. *A modified furnace for iron pan.* The furnace under 3 was subsequently modified by the insertion of fire bars in order to obtain underdraught. Matters were considerably improved by this modification.

5. *An American maple-sugar-making plant.* This was a plant imported from Messrs. Grimm & Co., of Vermont, U. S. A. It is an apparatus in common use in that country for the manufacture of maple sugar and has the reputation of being extremely economical of fuel. Photographs of the plant are to be seen in Plates I and II. The apparatus is portable, and the two furnaces are wholly of iron lined with fire brick. They are of course fitted with fire bars and burn either wood or coal. The evaporating pans (Plate II, fig. 2) are of heavily tinned iron. The juice flows from a storage tank seen in the right of Plate I, fig. 1, through a box which automatically gives any desired rate of flow into the corner of a long pan. This pan has two longitudinal divisions dividing it into three compartments, and its bottom instead of being flat is folded up into longitudinal corrugations in order to give a large heating surface. The juice having entered at the front corner end of one of these compartments flows forward and then through a hole in the neighbouring partition into the middle compartment. It flows back towards the front of the pan again where it is able to pass through a hole in the second partition and go into the third compartment. It flows forward down this compartment. By means of a syphon tube it is then automatically led into a smaller tinned iron pan with a transverse partition. It flows through a hole in the further end of this partition into a second compartment. It thence reaches another syphon and passes over into a third pan exactly similar to the second. Having passed through that the juice has become concentrated to about 1.1 specific gravity. The syphons are supposed to produce a cleaner syrup by not allowing the scum to pass on. The part of the apparatus so far described is called the evaporator. Its object is to concentrate the thin juice rapidly to a syrup, and the process is continuous, the juice as it is concentrating passing along through the pans the whole time and being continually drawn off at the part of the plant nearest the chimney. The hot juice is strained through felt and the syrup placed in the sugaring arch. This consists of a heavily tinned, deep, oblong iron pan set in an iron furnace fitted with fire bars and lined with fire brick. It is seen in the foreground of Plate II, fig. 1. The syrup is here concentrated to the necessary consistency for *gur*-making.

In making *gur* by this plant it will be seen that two furnaces are in use. Of course in the results set out below the fuel figure is the total fuel used in both furnaces.

6. *The sugaring arch* described above was used omitting the preliminary treatment in the evaporator.

The tables below show the results with each type of boiling plant and explain themselves.

1. THE ORDINARY COUNTRY FURNACE.

Tables (a), (b), and (c) set out the results obtained with country furnaces containing one, two, and four boiling pans respectively on each furnace. The tables explain themselves.

As is to be expected the amount of palm juice dealt with per hour is almost exactly proportionate to the number of boiling pans.

Thus a furnace with one boiling pan deals with 20 lb. of juice per hour. If there are two boiling pans, then 40 lb. of juice per hour can be dealt with. With 4 pans about 83 lb. of juice per hour were dealt with.

Proportion of fuel to juice. With only one pan per furnace this varies from 1.65/1.00 to 0.82/1.00 with an average for all the experiments of 1.23.

When the furnace has two boiling pans the proportion varies from 1.45/1.00 to 0.81/1.00 with an average for all the experiments of 0.96.

With 4 boiling pans per furnace the ratio varies from 1.00/1.00 to 0.75/1.00 with an average of 0.87. These figures apply only when wood is used as fuel. Date palm leaves seem to give much better results than wood, since, when they are used, the ratio varies from 0.53 to 0.69 with an average of 0.62.

Proportion of fuel to gur. With one pan per furnace this ratio varies from 15.0/1.0 to 6.8/1.0 with an average of 9.8. When the furnace had two boiling pans the ratio varied from 12.4/1.0 to 7.2/1.0 with an average of 8.6.

With 4 boiling pans on one furnace and wood fuel the ratio varies from 7.3/1.0 to 5.3/1.0 with an average of 6.4. When palm leaves are used as fuel the ratio ranges from 4.8/1.0 to 3.6/1.0 with an average of 4.3.

It is therefore quite obvious that a great wastage of fuel takes place if the boiling be carried out in furnaces having only one or two boiling pans. A furnace fitted with four boiling pans would apparently use only three-fourth the fuel which one fitted with only two boiling pans would in dealing with the same quantity of juice. Putting the value of wood at only 2½ annas per maund this would mean a saving of 5 annas per maund of *gur* on fuel alone.

Possibly the use of a larger number of pans might economize fuel to a larger extent, but obviously there must be a limit, and we do not think that increasing the number of pans beyond four is likely to bring about much further economy. It must be mentioned that the tappers seldom use furnaces containing less than 2 boiling pots but they very commonly use this type. Two boiling pans will deal with the juice of about 30 trees daily, so that if a man only owns this number of trees it means that he cannot use a furnace containing more than this number of boiling pans.

The high fuel value which date palm leaves have here calls for remark. It would seem that one part of date palm leaves is of just as much use for fuel as $1\frac{1}{2}$ parts of wood. The fact that the palm leaves can be completely burnt much more readily may account for its better fuel value. Then no doubt different kinds of wood have different fuel values.

Date palm leaves unfortunately are not available in sufficient quantities to last throughout the whole season for fuel. The leaves used are those removed from the trees in the beginning of the season when the trees are being prepared for tapping. By the middle or end of December this supply of leaves is exhausted, and for the remaining 2 to $2\frac{1}{2}$ months of the season other fuel has to be used.

It will be noticed that no experiments have been recorded in the case of country furnaces in which coal was used as fuel. It was found that coal could not be used in these furnaces owing to the want of underdraught.

(a) Only one boiling pan on furnace.

Date	Furnace used	Kind of fuel	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time of boiling	Juice dealt with per hour	Total sugar in juice %
13-1-16 ..	Cultivator's	Wood ..	lb. 61.4	lb. 7.5	8.2	lb. 50.6	0.82	6.8	hrs. 2.66	lb. 23	..
21-1-16 ..	Our furnace	Dried branches and palm leaves ..	..	8.1	..	*57.6	..	7.0	2.75	..	..
25-1-16 ..	Cultivator's	Wood ..	54.6	..	..	59.8	1.09	..	..	..	15.51
25-1-16 ..	Our furnace	" ..	53.0	6.8	7.8	78.3	1.48	11.5	..	..	..
26-1-16 ..	Cultivator's	" ..	71.9	8.6	8.4	78.8	1.10	9.2	4.83	15	..
26-1-16 ..	"	" ..	64.9	9.5	6.9	77.4	1.19	8.2	3.25	20	12.51
27-1-16 ..	"	Wood and palm leaves ..	68.4	8.6	8.0	(+ 61.6) (+ 22.0)	1.22	9.7	2.50	27	..
27-1-16 ..	"	Wood	73.0	7.5	9.8	*111.8	1.53	15.0	4.33	17	..
28-1-16 ..	"	"	71.3	7.9	9.0	96.8	1.36	12.2	3.17	23	..
28-1-16 ..	"	"	57.4	7.7	7.5	61.6	1.07	8.0	2.33	25	11.76
29-1-16 ..	"	"	74.4	9.5	7.9	82.9	1.11	8.8	4.50	17	..
29-1-16 ..	"	"	63.8	7.9	7.8	72.2	1.13	9.0	3.00	21	..
30-1-16 ..	"	"	75.5	7.7	9.8	103.0	1.36	13.4	..	..	10.54
30-1-16 ..	"	"	57.2	7.9	7.2	63.4	1.11	8.0	3.25	18	12.01
31-1-16 ..	"	"	74.6	9.0	8.2	84.7	1.13	9.4	..	..	11.72
31-1-16 ..	"	"	56.5	7.7	7.3	68.9	1.22	8.9	2.75	20	11.43
1-2-16 ..	"	"	72.2	8.1	8.8	91.1	1.26	11.2	3.17	23	11.99
1-2-16 ..	"	"	73.9	7.7	9.6	81.0	1.10	10.5	2.75	23	11.02
2-2-16 ..	"	"	66.2	9.0	7.3	79.9	1.27	8.9	..	..	..
2-2-16 ..	"	"	60.3	7.7	7.9	99.0	1.65	12.9	3.90	15	11.36
4-2-16 ..	"	"	49.1	6.4	7.7	72.6	1.48	11.4	3.25	15	12.43
AVERAGE			65.0	8.0	8.1	..	1.23	9.8	..	20	..

* Wood wgt. † Wood. ‡ Leaves.

(b) Two boiling pans on furnace.

Date	Cultivator's name	Kind of fuel	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time of boiling	Juice dealt with per hour	Total sugar in juice %
20-1-16 ..	Hailbot	Wood	lb. 125.0	lb. ....	....	lb. 140.8	1.13	....	hrs. 3.00	lb. 42	..
4-2-16 ..	"	"	137.7	15.40	8.9	111.3	0.81	7.2	3.50	39	11.35
5-2-16 ..	"	"	145.4	16.90	8.6	154.0	1.06	9.1	3.83	48	11.80
6-2-16 ..	"	"	137.7	13.90	10.0	112.9	0.82	8.1	3.33	41	11.23
Same juice as used in sugaring arch on this date.											
7-2-16 ..	"	"	96.1	11.21	8.6	139.7	1.45	12.4	2.83	34	11.35
9-2-16 ..	"	"	137.1	17.20	7.9	154.2	1.13	9.0	2.84	48	..
10-2-16 ..	"	"	140.8	16.70	8.4	127.6	0.91	7.6	4.23	33	..
10-2-16 ..	"	"	128.7	15.20	7.8	121.0	0.94	8.0	3.75	34	..
11-2-16 ..	"	"	126.7	15.40	8.2	120.1	0.95	7.8	..	..	..
11-2-16 ..	"	"	189.6	22.90	8.3	161.7	0.86	7.1	3.75	51	..
Same juice as used in sugaring arch on this date.											
12-2-16 ..	"	"	94.2	11.00	8.6	115.5	1.23	10.5	2.66	36	..
13-2-16 ..	"	"	92.4	15.20	6.1	129.8	1.40	8.5	2.75	34	..
15-2-16 ..	"	"	85.8	12.30	7.0	103.4	0.83	7.6	..	..	..
AVERAGE			126.0	15.30	8.2	..	0.96	8.6	..	40	..

(c) Four boiling pans on furnace.

Date	Cultivator's name	Kind of fuel	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time of boiling	Juice dealt with per hour	Total sugar in juice %
11-12-15..	Kayem	Wood	309.6	41.8	7.4	lb. 257*	0.83	6.1	hrs. 4.00	lb. 78	
12-12-15..	"	"	350.0	48.0	7.3	352*	1.00	7.3	4.00	88	
13-12-15..	"	"	322.0	42.4	7.6	296	0.92	7.0	3.50	92	
20-1-16 ..	Haibot	"	287.4	40.5	7.1	214	0.75	5.3	3.66	78	
21-1-16 ..	"	"	284.0	39.3	7.2	..	..	..	3.50	81	
AVERAGE			310.6	42.4	7.3	..	0.87	6.4	..	83	
11-12-15..	Haibot	Dried palm leaves	360.0	52.4	6.9	190	0.53	3.6	4.33	83	
12-12-15..	"	"	314.6	45.5	6.7	216	0.69	4.8	4.00	79	
13-12-15..	"	"	325.0	47.2	6.9	206	0.63	4.4	4.00	81	
AVERAGE			333.2	48.3	6.9	..	0.62	4.3	..	81	

* Weight includes 16 lb. leaves.

2. A MODIFIED COUNTRY FURNACE.

This has been described on page 100.

It was designed because it was felt that the greatest defect in the ordinary country furnaces was their want of underdraught. At the same time we wished to see if we could give the cultivators something very like their own furnace to start with but which was nevertheless an improvement. Our furnace cost less than Rs. 2 including the price of the earthen boiling pans.

Unfortunately only one experiment was done with wood fuel, but some half-a-dozen were carried out with coal as fuel. The results obtained were not very satisfactory except with some of the coal fuel experiments. Our general impression however was that the furnace burnt much better than the ordinary country one, but pressure of other work prevented us giving it a fair trial. The results are set out in the table. Two boiling pans were on the furnace in each case.

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour	REMARKS
		lb.	lb.		lb.			hrs.	lb.	
7-2-16 ..	Coal	94.6	10.3	9.1	33.0	0.35	3.20	2.5	38.0	
12-2-16 ..	"	150.9	22.2	6.8	46.2	0.31	2.10	2.8	53.3	
			Same juice as in Chinsurah pan of the date.							
13-2-16 ..	"	122.1	16.5	7.5	55.0	0.45	3.30	3.4	35.7	
14-2-16 ..	"	127.4	20.2	6.9	38.1	0.30	1.88	4.0	32.0	
15-2-16 ..	"	118.6	15.4	7.7	49.9	0.42	3.20	3.0	38.5	Much fuel left over unburnt.
18-2-16 ..	"	122.8	14.7	8.3	..	..	..	..	..
21-2-16 ..	"	..	13.4	..	29.7	..	2.20	..	..
17-2-16 ..	Wood	137.9	17.4	7.9	169.4	1.23	9.75	5.0	27.6	Wood wet.
			Same juice as used in sugaring arch on that day.							
AVERAGE.. omitting wood fuel experiment		125.0	16.3	7.7	..	0.37	2.60	..	38.0	

3 & 4. EXPERIMENTS WITH IRON BOILING PAN.

This was a round pan of a very shallow type. It has been found that by the use of a shallow pan a large amount of economy in fuel consumption may be brought about.

The experiments were carried out in two series.

Series I. The iron pan was placed over a furnace exactly like those of the cultivator's but large enough to fit the pan. Thus there was no underdraught. A small chimney made of kerosene tins was however fitted to the furnace at the side opposite the hole into which the fuel was fed.

Series II. The furnace used was a much deeper hole than above, and fire bars were placed across it half way up. It was also fitted with the chimney as before.

Only 4 experiments were carried out under Series I, two being with wood as fuel and two with coal. A larger number of experiments were carried out under Series II. All the results are recorded below :—

Series I. Ordinary country furnace.

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour	Total sugar in juice %
13-1-16 ..	Wood	305.8	37.6	8.1	265.5	0.87	7.06	..	..	..
28-1-16 ..	..	471.2	53.7	8.8	474.1	1.00	8.81	6.75	70	11.5
		Same juice as in maple furnace of date.								
AVERAGE		..	..	..	..	0.93	7.93	..	..	..
14-1-16 ..	Coal	362.0	44.9	8.1	*310.0	0.86	7.00	5.00	72	11.60
24-1-16 ..	..	271.6	31.7	8.7	138.6	0.51	4.38	3.42	81	10.85
		Same juice as in maple furnace of date.								

* 22 lb. wood also used.

A review of the results set out in the above table would show that the use of an iron pan on the ordinary local type of furnace possesses no advantage from the point of view of fuel economy over the ordinary method in which two earthen pans are used over a similar kind of furnace. It is further seen that the use of coal was unsuccessful.

The furnace hole was therefore deepened and fitted with fire bars on which to burn the fuel. The results then obtained are set out in the following table.

Series II. Furnace fitted with fire bars.

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour	Total sugar in juice %	REMARKS
29-1-16 ..	Wood	lb. 520.7	lb. 59.80	8.7	lb. 268.4	0.52	4.50	hrs. 4.25	lb. 122	11.24	
			Same juice as in the maple furnace of date.								
30-1-16 ..	"	659.6	66.40	9.9	381.5	0.58	5.00	5.75	115	11.62	
			Same juice as in the maple furnace of date.								
12-2-16 ..	"	373.1	35.20	10.6	206.8	0.56	5.90	3.66	102	12.84	Gur lost in transfer.
			Same juice as in the maple furnace of date (probably gur yield low).								
13-2-16 ..	"	505.8	65.80	7.7	334.0	0.66	5.10	5.66	89	12.62	
15-2-16 ..	"	584.1	74.60	7.8	312.2	0.59	4.60	7.33	80	..	Gur lost in transfer.
AVERAGE..		528.7	60.36	8.8	300.6	0.57	5.00	..	102	..	..
25-1-16 ..	Coal	329.6	40.50	8.1	154.0	0.47	3.70	4.00	82	11.80	
			Same juice as in maple furnace of date.								
26-1-16 ..	"	529.8	60.10	8.8	203.9	0.39	3.43	4.60	115	11.24	
			Same juice as in maple furnace of date.								
27-1-16 ..	"	603.5	60.90	9.9	189.2	0.31	3.10	5.66	107	11.50	
3-2-16 ..	"	767.4	84.70	9.0	178.0	0.23	2.10	5.66	136	11.74	
4-2-16 ..	"	812.9	83.80	9.7	195.8	0.24	2.36	7.60	107	11.34	
5-2-16 ..	"	655.8	64.20	10.6	191.4	0.29	3.00	6.16	106	13.58	
16-2-16 ..	" (Some wood)	323.8	47.10	6.9	126.7	0.39	2.70	4.50	72	..	
			Same juice as in maple furnace of date.								
AVERAGE..		574.7	63.10	9.0	..	1.33	2.91	..	104	..	

It will be seen from the above tables that the introduction of fire bars into the furnace brings about a very large economy in fuel. In the case of wood the ratio fuel/juice is only 0.57 and the ratio fuel/*gur* averages out at 5.0/1.0, that is, 57 lb. of fuel are sufficient to convert 100 lb. of juice into *gur*, or 5 parts of fuel are used in the manufacture of one part of *gur*.

A peculiar point to notice in these experiments with the iron pan is that the proportion of *gur* obtained from the juice is always much lower than with any other system of boiling we tried. Thus on an average 9 parts of juice were required to make one part of *gur*. In the country and maple furnaces the juice to *gur* ratio was only 7:8. Frequently we used some of the same juice on the same day for *gur*-making in the iron pan and also in the country or maple furnaces, but the iron pan always gave a distinctly lower yield of *gur*. It seemed to us that the reason was that it was difficult to clean all the *gur* off the pan at the end of the boiling, and therefore the weight of *gur* obtained was always less than it ought to have been. Further, our pan was so large that the men found it difficult to handle and frequently spilt some of the juice out of it.

The decrease in weight may be due to another reason. A considerable time elapses between the interval of removing the pan from the fire and the final transference of *gur* into the *bhars* (earthen storing pots). It is the general custom to allow the *gur* to cool some time before it is transferred into the *bhars*. But in the case of this pan it has been noticed that the temperature of *gur* in the pan after being removed from the fire steadily increases for a time and this increase goes on so far as 120°—123°C. (scarcely below 120°), whereas the general temperature at which the *gur* is taken out as finished is about 115°C. The pan being a metallic one naturally remains hotter as compared to the earthen *jalas* used in the country process. The *gur* made in the iron pan would therefore contain less water, and this would explain the lower out-turn.

5. AN AMERICAN MAPLE-SUGAR-MAKING PLANT.

This has been described on page 101.

Owing to the difficulty of obtaining the amount of wood required, most of the experiments were done with coal fuel. A few experiments were made in which wood was mainly used. All the results are set out in the table below.

Date	Fuel used	Weight of juice lb.	Weight of gur lb.	Ratio of juice to gur	Weight of fuel lb.	Ratio of fuel to juice	Ratio of fuel to gur	Time hrs.	Juice dealt with per hour lb.	Total sugar in juice %	REMARKS
8-12-15..	Wood Some coal	697.0 ..	92.5 ..	7.40 ..	320 80	0.50 0.09 (0.72)	3.45 0.86 (5.60)	5.50	127 .. ..	.. .. ..
9-12-15..	Wood Some coal	734.0 ..	96.0 ..	7.60 ..	240 20	0.33 0.03 (0.40)	2.50 0.20 (3.00)	.. .. ..	.. .. ..	.. .. ..
10-12-15..	Wood Some coal	881.2 ..	108.0 ..	8.15 ..	300 40	0.34 0.04 (0.44)	2.80 0.37 (3.72)	.. .. ..	.. .. ..	.. .. ..
16-12-15..	Wood Some coal	732.2 ..	104.0 ..	7.26 ..	440 50	0.59 0.07 (0.76)	4.27 0.50 (5.52)	6.66	113 .. ..	.. .. ..	Wood wet, much trouble.
17-12-15..	Wood Some coal	738.0 ..	98.0 ..	7.53 ..	450 90	0.61 0.12 (0.91)	4.60 0.92 (6.90)	.. .. ..	.. .. ..	.. .. ..
18-12-15..	Wood Some coal	804.5 ..	100.0 ..	8.04 ..	640 100	0.80 0.12 (1.10)	6.40 1.00 (8.40)	.. .. ..	.. .. ..	12.10	
11-1-16 ..	Wood	1,047.0	140.6	7.45	1004.2	0.97	7.34	8.32	126	11.52	Furnace still wet. Second day in field.
14-1-16 ..	Wood Some coal	1,459.0 ..	198.4 ..	7.35 ..	583 319	0.42 0.22 (0.97)	2.94 1.60 (6.94)	10.16 ..	145 ..	11.60 ..	
AVERAGE..		890.0	117.2	7.60	..	*0.66	*5.99	..	128	..	

* These results have been obtained after multiplying any coal used in each experiment by 2.5 (many experiments having shown coal to be about 2.5 times as useful as fuel as wood). The figure thus obtained was added to the amount of wood used, and the result is shown in brackets in each case.

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel		Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour	Total sugar in juice %	REMARKS
27-11-15..	Coal	lb. 264	lb. 36.5	7.23	lb. 120.0	..	0.45	3.30	hrs. ..	..	..	Furnace new and wet. Small amount of juice.
29-11-15..	"	750	102.0	7.35	240.0	..	0.32	2.35	..	..	..
19-12-15..	Coal Some wood	800	102.4	7.81	190.0 50.0	Coal Wood	0.24 0.06	1.85 0.50	..	..	12.14	
10-1-16 ..	Coal Some wood	..	102.3	..	283.3 39.6	Coal Wood	..	2.80	7.00	..	..	First day in field. Furnace wet.
12-1-16 ..	Coal Some wood	1,394	184.6	7.55	345.0 79.0	Coal Wood	0.25 0.06	1.99 0.43	8.33	166	11.41	
13-1-16 ..	Coal Some wood	937	124.1	7.55	246.4 37.4	Coal Wood	0.26 0.04	1.99 0.30	6.66	141	11.89	
16-1-16 ..	Coal	2,138	298.0	7.17	616.0	..	0.29	2.06	10.50	204	11.30	
17-1-16 ..	"	2,015	283.0	7.10	607.0	..	0.30	2.14	10.33	195	11.32	
18-1-16 ..	"	2,137	293.0	7.40	625.0	..	0.29	2.13	..	..	11.34	

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour	Total sugar in juice %
19-1-16 ..	Coal	lb. 2,438	lb. 303.0	8.04	lb. 678.0	0.28	2.23	hrs. 14.00	lb. 174	10.70
20-1-16 ..	"	1,082	224.8	7.48	198	..	0.05	8.42	200	10.86
21-1-16 ..	"	1,214	161.5	7.52	22.0	..	2.30	7.25	168	11.80
22-1-16 ..	"	1,269	160.8	7.89	341.0	0.28	2.11	..	..	10.90
23-1-16 ..	"	1,067	128.7	8.30	22.0	..	2.31	8.00	133	10.96
24-1-16 ..	"	891	126.9	7.50	372.0	0.27	2.26	7.42	120	10.85
25-1-16 ..	"	980	130.0	7.54	290.4	0.36	2.53	7.25	135	11.08
26-1-16 ..	"	1,148	160.4	7.16	321.0	0.29	2.20	8.16	141	11.24
27-1-16 ..	"	1,271	170.9	7.40	Same juice as in Chinsurah pan of the date.	0.27	2.00	7.33	173	11.50
28-1-16 ..	"	1,148	147.4	7.92	Same juice as in Chinsurah pan of the date.	0.31	2.40	9.33	117	11.50
29-1-16 ..	"	1,100	141.7	7.75	354.2	0.32	2.48	..	..	11.24
30-1-16 ..	"	1,134	145.0	7.86	351.6	0.27	2.09	8.60	132	11.62
31-1-16 ..	"	1,326	194.9	7.83	303.6	0.28	2.15	9.25	165	11.68
1-2-16 ..	"	1,204	163.2	7.37	420.2	0.31	2.30	8.83	136	12.29
2-2-16 ..	"	1,191	150.5	7.93	376.2	0.35	2.83	..	..	11.97
AVERAGE		1,291	159.3	7.60	..	0.30	* 2.38	..	156	..

* Wood used is neglected since difference made is so slight. These results will be considered later.

6. EXPERIMENTS WITH THE SUGARING ARCH.

As already explained above, this is merely the deep, oblong, finishing pan of the maple sugar furnace. It rests on its own iron furnace which is fitted with fire bars and lined with fire bricks. It is seen in the fore part of Plate II, fig. 1.

The table summarizes the results with this plant.

Date	Fuel used	Weight of juice	Weight of gur	Ratio of juice to gur	Weight of fuel	Ratio of fuel to juice	Ratio of fuel to gur	Time	Juice dealt with per hour.	Total sugar in juice %
17-2-16 ..	Wood	lb. 475.0	lb. 59.6	8.0	lb. 378.0	0.79	6.30	hrs. 9.60	lb. 50	..
Only one experiment done with wood as fuel.										
6-2-16 ..	Coal	549.1	74.1	7.4	173.8	0.32	2.40	6.83	84	11.23
Same juice as per country bain experiment (alum v. H ₂ 30).										
7-2-16 ..	"	403.6	55.4	8.0	136.4	0.34	2.46	5.66	71	11.88
8-2-16 ..	"	504.9	66.7	7.6	195.8	0.39	2.90	6.00	84	12.38
Same juice as in modified country furnace.										
9-2-16 ..	"	544.1	70.8	7.7	140.8	0.26	1.98	7.33	74	..
10-2-16 ..	"	715.4	90.6	7.9	188.1	0.26	2.08	8.00	89	..
Same juice as used in country furnace experiment of the date.										
11-2-16 ..	"	781.0	107.6	7.2	253.0	0.32	2.35	8.42	93	..
AVERAGE .		583.0	77.5	7.6	..	0.31	2.36	..	82	..

SUMMARY.

The following table summarizes the average results of each method of boiling with wood fuel.

Method of boiling	Ratio of fuel to juice	Ratio of fuel to gur	Juice dealt with per hour	Number of experiments
Country system, 1 pan	1.23	9.80	lb. 20	21
Country " 2 pans	0.96	8.60	40	13
Country " 4 "	0.87	6.40	82	5
Iron pan, country furnace	0.93	7.93	70	2
Iron pan, furnace with fire bars	0.57	5.00	102	5
Maple sugar outfit	0.66	5.99	128	9
Sugaring arch	0.79	6.30	50	1

These results would show that in the country method of boiling the use of 4 pans is much more economical of fuel than the use of 2 pans, requiring only about 75 per cent. of the fuel required by the latter to make the same quantity of *gur*. When only 1 pan is used per furnace there is a still greater wastage of fuel.

The iron pan used on a furnace fitted with fire bars has given results far superior to any other methods of boiling, being distinctly an improvement on the maple sugar outfit.

As regards the juice dealt with in a given time, that is, the rapidity of concentration, in the case of the country system the amount seems almost directly proportioned to the number of pans in use. Thus with 1, 2, and 4 pans the number of lb. of juice dealt with per hour was 20, 40, and 83 respectively. The Chinsurah pan dealt with 102 lb. per hour on an average.

RECOMMENDATIONS.

1. It seems that it is possible to exercise a considerable economy of fuel in the native production of palm *gur*. Further work should therefore be carried out with the object of evolving the most suitable type of furnace.

2. For the present the indications are that the introduction of shallow iron pans in combination with a furnace fitted with iron bars would cause considerable economy in fuel consumption.

3. In some of our experiments, notably with the maple sugar plant and occasionally with the iron pan, we have been able to make a maund of *gur* with the consumption of only about 2 maunds of coal. This means that 1 maund of coal is about equivalent as fuel to $2\frac{1}{2}$ maunds of wood.

If a good furnace could be designed to burn coal there are many places where it would pay to use coal as fuel instead of wood, since coal could be obtained in many of the sugar districts at 6 annas* per maund of 82 lb.

4. Where fuel is getting scarce it might be worth while planting *Casuarina* trees in groves in certain areas as is done in certain parts of Madras. These trees are quick growers and do very well in Bengal.

* Pre-war rate.

REMARKS

Fuel wet.

PART IV. CONCLUSIONS.

1. The experiments show that the practice of liming the collecting pots before collection of juice should be introduced into the palm sugar districts of Bengal. The benefits which would be derived from this practice are :—

(a) The *gur* made would be of a much better quality from the refining point of view, because the lime destroys living organisms in the juice and also prevents the action of the enzyme invertase which converts the cane sugar into glucose and fructose.

(b) The yield of *gur* would be increased to some extent, for, owing to the reason set out under (a), fermentation of the sugar would be checked.

(c) The juice flowing in the day time could be collected and used for *gur* production. At present it is only rarely collected and even then only made into a sticky, non-crystalline treacle. It has been shown by actual measurements that if this day juice were used for *gur*-making it would mean an increase in yield of *gur* of something like 20 per cent.

2. The dark colour of date palm *gur* is due to the presence of alkaline constituents in the juice. By neutralizing this acidity with any acid substance just before boiling a perfectly light-coloured *gur* may be obtained. Apart from the common mineral acids tamarind fruit extract or alum may be used for this purpose.

3. The present furnaces in use for the manufacture of *gur* are very wasteful of fuel and there is room for work in designing more economical furnaces.

4. The native palm sugar refining industry is still of very large dimensions in Bengal. It is very wasteful and slow. It would seem well worth giving a good trial to centrifugals for doing this work. We made quite a good quality of sugar by the use of centrifugals.

5. Our further work on this industry only confirms our previous opinion that a thorough trial should be given to a scheme for producing white sugar or a good grade of raw sugar directly from the juice on the factory scale. We are convinced that the wild date palm is a very cheap source of sugar.

CHOLAM (*A. SORGHUM*) AS A SUBSTITUTE FOR BARLEY IN MALTING OPERATIONS

BY

B. VISWANATH,

T. LAKSHMANA ROW, B.A.,

AND

P. A. RAGHUNATHASWAMI AYYANGAR, DIP. AG.,

Assistants to the Government Agricultural Chemist, Madras.

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At the Madras Exhibition of 1917, the Government Agricultural Chemist exhibited a series of malted foods of the type of Benger's and Mellin's foods and Horlick's malted milk, which were prepared by the use of malt obtained from *cholam*¹ (*Andropogon Sorghum*) and *ragi* (*Eleusine coracana*). The use of these cereal grains for the preparation of malts was necessitated by the fact that barley is not produced in South India with the exception of a comparatively small quantity on the Nilgiri hills.

Experiments made in Europe and America with barley, maize, wheat, rye, and oats had shown that barley was the grain best suited for purposes of malting. The malting values of the various grains examined were² :—

Barley	...	...	...	1.00
Oats	...	...	...	0.30
Maize	...	...	...	0.28
Rye	...	...	...	0.93
Wheat	...	...	...	1.08

Wheat malt, though slightly better than barley, has been discarded for general use as being too costly, so that barley is the grain almost universally employed for malting purposes.

¹ Synonyms :—

English—Great millet.

North Indian—Juar.

Tamil—Cholam.

Telugu—Jonna.

Kanarese—Jolah.

Burmese—Pyong [Watt. *Dict. Econ. Prod. India.*]

² Martin, G. *Industrial Organic Chemistry*, page 286.

This paper deals with the investigations carried out with the object of finding a satisfactory substitute for barley from amongst the common South Indian cereals. The following obtained from the Central Farm, Coimbatore, were examined for their malting capacities: *paddy* (*Oryza sativa*), *cholam* (*Andropogon Sorghum*), *ragi* (*Eleusine coracana*), *tenai* (*Setaria italica*), *maize* (*Zea Mays*), and *cumbu* (*Pennisetum typhoideum*).

PREPARATION AND EXAMINATION OF THE MALTS.

The malts were prepared in each case in the laboratory in the following manner. A quantity of the grain was soaked in water for 12 hours, the water being removed twice during the period, at the end of which it was completely drained off. The swollen grains were then transferred to germinating trays, and germination was allowed to proceed as uniformly as possible. The temperature of germination was about 28°C. At the end of 60 hours, the radicles had developed to about $1\frac{1}{2}$ times to twice the length of the grain, and the plumules were just showing up. The germination was, at this stage, arrested by cutting off the supply of moisture. The grains were first dried in the shade for a day, and then at 50°C. for two days in a draught oven. The radicles had, by this time, dried up, and could easily be removed by rubbing and sieving.

The degree of starch hydrolysis effected by each of the malts was taken as the basis in estimating their relative efficiency. Two methods were adopted in determining the activity of the malts in the starch solution so that the one might be a check against the other. They were (a) titration of the products of hydrolysis of starch against Fehling's solution, and (b) the testing of the products of hydrolysis by their colour reactions with iodine, these reactions being blue when starch is present, red, violet, or purple when dextrine is present, yellowish when hydrolysis is almost complete, and colourless or yellow when hydrolysis is complete.

The malts were ground in a laboratory mill and 3 grams of each were extracted with 50 c.c. of distilled water for 5 hours at the laboratory temperature (28°C.-30°C.) and filtered through a dry filter. Ten c.c. of the filtrate were added to 50 c.c. of a 2 per cent. solution of Lintner's soluble starch and kept for one hour at room temperature. At the end of this period further diastatic action was stopped by raising the solutions to the boil and, after cooling, they were made up to 100 c.c. and titrated against Fehling's solution. The figures obtained required a correction due to the reducing power of the malt extract added. This was determined in each case by means of a blank

experiment with the malt extract alone and the corrected values corresponding to the actual products of hydrolysis were then deduced.

TABLE I.

Showing the relative efficiency of various malts as judged by Fehling's solution.

Malts			Total reduction values in terms of c.c. Fehling's solution	Reduction values of malt extracts used in terms of c.c. Fehling's solution	Corrected reduction values in terms of c.c. Fehling's solution	Relative efficiency. Cholam = 1.00
Cumbu	...	...	47.6	8.3	39.3	0.71
Maize	...	...	52.1	9.4	42.7	0.78
Tenai	...	...	56.8	5.9	50.9	0.93
Cholam	...	...	66.7	11.6	55.1	1.00
Paddy	...	...	66.7	9.4	57.3	1.04
Ragi	...	...	80.0	19.7	60.3	1.09

Malt extracts prepared in the same manner were similarly treated with soluble starch in test tubes and tested with iodine at intervals of quarter of an hour with the following results :—

TABLE II.

Showing hydrolysis of starch as judged by colour reactions with iodine.

Name of malt	COLOUR REACTIONS WITH IODINE AT THE END OF			Inference
	15 minutes	30 minutes	45 minutes	
Cumbu	Blue	Blue	Blue	Hydrolysis incomplete, starch present.
Tenai	Blue	Blue	Blue	Ditto.
Cholam	Violet blue	Yellowish	Yellow	Hydrolysis complete.
Paddy	Blue	Reddish blue	Reddish blue	Hydrolysis incomplete, dextrine present.
Ragi	Violet blue	Yellowish	Yellow	Hydrolysis complete.

It will be seen from the above that the diastatic activity of *paddy*, *cholam*, and *ragi* is greater than that of *cumbu*, *tenai*, or *maize*. These latter grains

were, therefore, eliminated from further consideration, and the *paddy*, *cholan*, and *ragi* malts subjected to further comparative tests.

As a basis for the comparison of these grains, it was sought to determine approximately the stage of germination at which diastatic activity was at its maximum for each kind of grain and, with this object in view, samples were withdrawn from time to time during the course of germination and the following factors determined in each case:—

- (i) The average length of the radicle.
- (ii) The specific gravity of the aqueous extract.
- (iii) The diastatic activity of the extracts when made under uniform conditions as measured by the iodine test.

The results (see Table III) show that *cholan* and *ragi* give an extract of greater specific gravity than *paddy* and at the same time their diastatic hydrolysis has been carried to completion whereas that of *paddy* has remained incomplete. Consequently they are better suited for malting than *paddy* which was, therefore, eliminated from further consideration. At this stage further experiments with *ragi* were also given up as it was considered that the smallness of the grain and its tendency to form a felted mass in the malting trays detracted from its usefulness as a malting grain.

CHOLAM AND BARLEY COMPARED.

The choice of a suitable grain being therefore restricted to *cholam*, the next step in our investigation was a comparison between *cholam* and barley, the former being the best suited South Indian cereal, and the latter the one most generally used by maltsters. The barley used for these experiments was obtained from the Kaity branch of the United Breweries, Ltd., Nilgiris, who had imported it from the Punjab.

Barley malt is generally prepared at a temperature of about 15°C., whereas the temperature actually available at Coimbatore is 28–30°C.; consequently, for purposes of comparison, barley and *cholam* malts were prepared—

- (i) in a cool incubator at a temperature of 18–20°C., and
- (ii) at the laboratory temperature of 28–30°C., and subjected to comparative tests.

The quality of a malt is usually judged from the quantity of water-soluble matter it is capable of yielding, and its degree of acidity in terms of lactic acid. It was, therefore, thought desirable at the outset to test our malts for these factors usually connoted by the term "soundness."

The water-soluble matter was determined by stirring up 25 grams of each malt with 200 c.c. of water which was brought to the boil and kept in the steam oven for one hour. After cooling, the volume was made up to 250 c.c., and the whole filtered through a dry filter. Fifty c.c. of the filtrate were evaporated to dryness and weighed, and the weight of the extract obtained was calculated to 100 grams malt.

TABLE IV.

Showing percentage of soluble matter in Cholam and Barley malts.

					Cholam	Barley
Moisture	...	...	...	...	5.29	5.95
Weight of dry residue in 50 c.c. filtrate			...	...	3.72	3.40
Weight of soluble matter in 100 grams malt			...	...	74.40	68.00
Weight of soluble matter calculated on the dry malt			...	...	78.50	72.30

The acidity of the malts was determined according to Allen's method¹ by extracting 50 grams of the ground malt with 100 c.c. of water for 30 minutes,

¹ Allen. *Comml. Organic Analysis*, vol. I, page 327.

filtering and titrating the filtrate against N/10 KOH with litmus as indicator.

TABLE V.
Showing acidity of Cholam and Barley malts.

Malt					Temperature of malting	Acidity calculated as per cent. lactic acid
Barley malt from Nilgiris	...	...	...	...	.....	0.19
Barley malt prepared in the laboratory	...	...	...	...	18–20°C.	0.19
Barley malt	do.	...	...	...	28–30°C.	0.16
Cholam malt	do.	...	...	...	18–20°C.	0.33
Cholam malt	do.	...	...	...	28–30°C.	0.28
Cholam malt	do.	...	...	...	28–30°C.	0.25

A malt is considered sound¹ when it yields about 70 per cent. of water-soluble extract, and contains less than 0.4 per cent. free acid (calculated as lactic acid), so that the malts which were prepared in the laboratory were sound in the technical sense, and the scope of the investigation was extended, therefore, to include the following :—

- (a) Comparison between the diastatic activities of *cholam* malts prepared at two different temperatures, viz., 18–20°C. and 28–30°C., and during various stages of germination.
 - (b) Comparison between the diastatic activities of *cholam* and barley malts prepared at 18–20°C. and 28–30°C.
 - (c) A preliminary investigation of the products of starch hydrolysis by *cholam* malt.
- (a) *Comparison between the diastatic activities of Cholam malts prepared at two different temperatures and during various stages of germination.*

The malts were prepared in the manner already described at two different temperatures, viz., 18–20°C. in a cool incubator, and 28–30°C. which was the laboratory temperature. At intervals during the process of germination samples were withdrawn, the length of the radicles measured, and the prepared malts were examined for their diastatic activity.

¹ Allen. *Comml. Organic Analysis*, vol. I, page 327. Also, Lunge. *Technical Methods of Chem. Analysis*, vol. III, part II.

TABLE VI.

Showing relative diastatic activities of Cholam malts prepared at 18–20°C. and 28–30°C., and at different stages of germination.

Hours after soaking the grain	TEMPERATURE OF PREPARATION 18–20°C.			TEMPERATURE OF PREPARATION 28–30°C.		
	Length of radicle in c.m.	c.c. sugar solution required for reducing 10 c.c. Fehling's solution	Colour reaction with iodine after 45 minutes' hydrolysis	Length of radicle in c.m.	c.c. sugar solution required for reducing 10 c.c. Fehling's solution.	Colour reaction with iodine after 45 minutes' hydrolysis
66	0.3	196.0	Blue	2.1	60.0	Bluish violet
90	1.0	132.0	Violet	3.3	52.0	Pale, but distinct violet
114	2.2	63.5	Very pale violet	7.5	55.0	Ditto.
138	3.6	54.0	Yellow	..	..	.....
162	..	57.0	Yellowish	..	..	.....

These results indicate that the diastatic activity reaches a maximum when the radicle grows to a length of about 3 c.m., and, as is to be expected, that the growth is quicker at a higher temperature than at a lower one.

(b) Comparison between Cholam and Barley malts prepared at (i) 28–30°C. and (ii) 18–20°C.
(i) 28–30°C.

Two grams of each of the *cholam* and barley malts prepared at 28–30°C. were extracted for 3 hours at room temperature with 100 c.c. of water, filtered, and 1 c.c. of each of the extracts was added to a number of test tubes containing 5 c.c. of 4 per cent. soluble starch and tested with iodine every quarter of an hour.

TABLE VII.

Showing the relative diastatic activities of Cholam and Barley malts by iodine tests.

Duration of experiment	Cholam malt	Barley malt
15 minutes	Violet with light blue	Blue
30 "	Violet with faint blue	Blue
45 "	Violet	Blue
60 "	Violet	Blue
75 "	Yellowish	Violet with light blue
90 "	Yellow	Violet with faint blue
105 "	.....	Yellow

Again 1 c.c. of each of the malt extracts was added to two separate lots of 50 c.c. of the soluble starch, and at the end of one hour hydrolysis was arrested by raising the solutions to the boil. The mixtures were cooled, made up to 100 c.c., and titrated against Fehling's solution.

TABLE VIII.

Showing the relative diastatic activities of Cholan and Barley malts by the copper reduction method.

Malt	c.c. sugar solution required for reducing 5 c.c. Fehling's solution	
	Experiment A	Experiment B
Cholan malt	16.5	16.5
Barley malt	13.0	13.0

(ii) 18–20°C.

Experiments similar to the preceding were made with *cholan* and barley malts prepared at 18–20°C., and the results are given below:—

TABLE IX.

Showing relative diastatic activities of Cholan and Barley malts prepared at 18–20°C.

Malt	c.c. sugar solution required for reducing 10 c.c. Fehling's solution	Colour reaction with iodine after 45 minutes' hydrolysis
Cholan malt	54.0	Yellow
Barley malt	52.5	Violet

The results tabulated in Tables VII, VIII, and IX show that *cholan* malt is diastatically more active than barley malt according to the iodine test. Quite the reverse, however, is indicated by the copper reduction method. This apparent discrepancy may be explained in the following manner.

It is possible that the hydrolysis of the starch takes place at a greater rate with *cholan* malt than with barley malt, and that comparatively more dextrine and less sugar are produced with the former than with the latter. It is also possible that the dextrine formed by the action of *cholan* malt belongs to the class of dextrines not precipitated or coloured by iodine, though capable of reducing Fehling's solution. If this is the case, then the difference in the

behaviour of the two malts with the two reagents would be explained, as the cupric-reducing power of dextrine is much less than that of maltose. If this view is correct, then the specific rotation of the products of hydrolysis of starch should be greater with *cholam* malt than with barley malt, dextrine having a higher specific rotatory power than maltose; whereas the cupric-reduction power would be greater in the case of barley malt.

In order to obtain information on these points, the following experiments relating to the nature of the starch conversion products of *cholam* and barley malts were carried out. O'Sullivan¹ has pointed out that in the hydrolysis of starch by barley malt more dextrine than maltose is produced at higher temperatures. It was therefore thought desirable to conduct the experiment at two different temperatures.

Twelve grams each of *cholam* and barley malts were extracted with water at the laboratory temperature (28–30°C.) for 3½ hours and filtered. Fifty c.c. of 8 per cent. soluble starch solution were taken in two 100 c.c. flasks to which 3 c.c. of the malt extracts were next added, and the whole maintained at room temperature for 3½ hours. To two other 100 c.c. flasks each containing 50 c.c. of the soluble starch, 3 c.c. of the extract were similarly added, and the whole kept at a temperature of 65–70°C. for 45 minutes only. At the end of these periods the two sets of solution were raised to the boil, cooled, made up to 100 c.c. and filtered. The percentage of total solids, the specific rotation, and the cupric-reducing power of each of the filtrates were then determined. In the table below, the cupric-reduction values (R) are referred to maltose (as is usual in the case of starch conversion products), taking that of maltose = 100.

TABLE X.

Showing the optical rotation and the cupric-reducing powers of the products of hydrolysis of starch by Cholam and Barley malt extracts at 28–30°C. and 65–70°C.

Factor for the starch-conversion product = 3.977.

Name of malt	Temperature of hydrolysis	% Solids	$[\alpha]^{20}_{D. 3.977}$	R = % that of maltose
Cholam	28 – 30° C.	3.81	148.12	89.1
	65 – 70° C.	3.85	150.83	85.5
Barley	28 – 30° C.	3.79	140.13	92.0
	65 – 70° C.	3.87	141.10	90.0

¹ O'Sullivan *J. C. S.*, T. 1876.

It is seen that the percentage of total solids in the two sets of solutions being almost the same, the specific rotation of the products of hydrolysis, both at low and high temperatures, is greater with *cholan* malt than with barley malt whereas quite the reverse is the case with the cupric-reducing power. The above experiment would thus appear to bear out the view previously expressed that the proportion of dextrine to sugar is greater in the case of *cholan* than in the case of barley malt.

It is also seen that the observation made by O'Sullivan¹ that comparatively more dextrine than sugar is formed when the hydrolysis takes place at higher temperatures (65–70°C.), is even more pronounced in the case of *cholan* than barley.

(c) *A preliminary examination of the products of starch hydrolysis by Cholan malt.*

It has been shown so far that *cholan* malt is diastatically more active than barley malt under the conditions of our experiments; for *cholan* to take the place of barley in malting operations, it is of importance that the starch-conversion products should be similar in both the cases. A preliminary examination, therefore, was made of the products formed as a result of hydrolysis by *cholan* malt.

Ten grams of soluble starch were stirred with 200 c.c. of boiling water, cooled, and the aqueous extract from 10 grams of *cholan* malt added. A little toluene was put into the flask, and the whole kept at laboratory temperature overnight. The next morning the liquid was raised to the boil to coagulate the proteins in the malt extract, cooled and filtered. The filtrate was reduced to a small volume on the water bath, and 92 per cent. alcohol was added to precipitate dextrine, a small quantity of which separated out as a white gelatinous mass coloured red by iodine, and was again filtered. The alcohol was distilled off *in vacuo* and the sugar solution concentrated. A portion of the concentrated syrup was made up to 100 c.c. Twenty-five c.c. of this were pipetted off into a small flask, 2 c.c. of strong hydrochloric acid were added and the sugar was hydrolysed on the water bath for one hour. At the end of this period, the hydrolysed sugar solution was cooled, neutralized with caustic soda made up to 50 c.c., and examined both by optical and copper-reduction methods. Another portion of 25 c.c. of the diluted sugar solution was made up to 50 c.c., and similarly examined for purposes of comparison.

¹ O'Sullivan. *loc. cit.*

TABLE XI.

Showing the results of examination of the starch-conversion products of Cholam malt before and after hydrolysis.

	Before hydrolysis	After hydrolysis	Ratio. Before hydrolysis : After hydrolysis
Schmidt and Haensch polariscope scale reading (200 m.m. tube)	+ 60.4	+ 24.0	2.52
c.c. Fehling's solution reduced by 100 c.c. of the sugar solution	52.1	80.6	0.65

It will be noticed that, after hydrolysis of the sugar solution, there is a considerable fall in the polariscope readings, and a large increase in the quantity of Fehling's solution reduced. This behaviour accords with that of maltose when hydrolysed into dextrose. The specific rotatory power of maltose and dextrose¹ being 138.0 and 52.76 respectively, the ratio of the polariscope readings before and after hydrolysis in the case of maltose solution would be $\frac{[\alpha]_D}{[\alpha]_{D'}} = \frac{138.0}{52.76} = 2.62$. Similarly, the ratio of the quantities of Fehling's solution reduced would be, according to the cupric-reducing powers, $\frac{K}{K'} = \frac{61}{100} = 0.61$. These figures correspond very nearly with those entered in column 4. It is thus clear that the solution under examination behaved as though it was one of maltose.

With phenylhydrazine hydrochloride, maltosazone and glucosazone were produced.

We propose to continue this part of the investigation.

From a consideration of the foregoing results, we feel justified in concluding that *cholam* may be used wholly or partially as a substitute for barley in malting operations. The absence of a sufficient proportion of husk in the grain is perhaps a disadvantage with *cholam*, but this defect can possibly be remedied by admixture with malted paddy or bran. *Cholam* is much cheaper and more largely available in India than barley and can, therefore, be used extensively.

Foods of the types of Mellin's food, Horlick's malted milk, malt extract, and beer were prepared by us in the laboratory and submitted to the Madras

¹ Browne, C. A. *Handbook of Sugar Analysis*.

Exhibition of 1917. The details of the methods of preparation and the nature of the apparatus used are being published as a separate paper.¹

SUMMARY.

The results obtained so far may be summarized as follows :—

- (1) *Cholam* is better suited for malting purposes than the other common South Indian cereals experimented with.
- (2) *Cholam* malt extract hydrolyses soluble starch at a greater rate than barley malt extract.
- (3) In the case of hydrolysis of starch by *cholam* malt the proportion of dextrine to sugar produced is greater than in the case of barley malt compared under identical conditions.
- (4) The products of starch hydrolysis by *cholam* malt consist, as with barley malt, largely of maltose and dextrine.

We would like to express our thanks to Dr. W. H. Harrison for suggesting the investigation, and to Mr. M. R. Ramaswami Sivan for help during the course of this work.

¹ *Agriculture Journal of India*, vol. XIV, pt. I.

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THE PHOSPHATE REQUIREMENTS OF SOME LOWER BURMA PADDY SOILS.

BY

F. J. WARTH, M.Sc., B.Sc.,

Agricultural Chemist to the Government of Burma,

AND

MAUNG PO SHIN,

Assistant to the Agricultural Chemist to the Government of Burma.

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THE work consisted of soil analyses combined with suitable pot culture tests to show up deficiencies in phosphoric acid.

I. SOIL ANALYSES.

Regarding the method of soil analysis employed it should be stated that extraction was effected by continuous boiling of the ignited soil with concentrated HCl for 8 hours. The soluble silica was determined in the residue by boiling with Na_2CO_3 solution. Total phosphoric acid was determined by extraction of the unheated soil with nitric-hydrochloric acid. Complete results are given in the appendix (Table A).

Allowing for differences due to texture the soils fall according to chemical composition into a few distinct groups. The soils around Nyaunglebin and Daiku are evidently fairly new compared with most of the others. These soils, though low in lime, are high in potash and phosphoric acid. The soils of the Hlaing valley along the Prome line are quite as new as the above. They are high in magnesia, potash, and phosphoric acid, but low in lime.

From the neighbourhood of Toungoo we get samples of soils which are probably much older. They have certainly suffered extensive leaching out and are distinctly poor in lime, potash, magnesia, and phosphoric acid.

Finally, the soil samples of Pegu, Insein and Hanthawaddy districts have given almost invariably very low lime, potash, magnesia, and phosphoric acid figures. Most of these soils are undoubtedly old and have suffered severe leaching out. The newer soils are neutral or acid. The remainder are all acid, the acidity varying to a degree which is at present inexplicable. It has not been found to conform with any agricultural characters so far studied.

In addition to the marked variation in phosphoric acid content as we pass from one soil area to another, there is also a definite relationship between phosphoric acid content and soil texture irrespective of the source of the soil. This is by no means surprising but the extent of this correlation in the case of the Lower Burma soils is worth noting. It is clearly shown in a table given later (Table V) in which the soils have been divided into groups according to texture. (For this purpose it is assumed that the texture of a soil is roughly indicated by the soluble silica figures.) This table shows that the available phosphoric acid as determined by citric acid extraction increases generally with the total phosphoric acid content, the availability increasing on the whole more rapidly than the total phosphoric acid.

Some figures for available phosphoric acid are noticeably peculiar, *e.g.*, Daiku and Prome; Pyinbongyi A and Thilawa. If the availability data are significant, growth of plants on these soils should bring out noticeable differences.

The phosphoric acid content of Hmawza soil is quite unique.

II. POT CULTURE TESTS.

These were manurial trials to determine the effect of phosphoric acid and nitrogen, separately and combined. Potash was also tested but gave in no case conclusive figures.

Each manurial test was made in four pots, and, as a check, four unmanured pots were also tested with each soil. Some typical photographs of pots are shown in Plates I—IV. These illustrate the regularity of growth and the satisfactory maturing of the crop.

Culture tests with all the soils could not be carried out in one year. The work was distributed over three seasons, and therefore both the rate of development and the final crop yields are considerably affected by climate.

In one sense this is undoubtedly a disadvantage as it prevents a close comparison of all data. On the other hand, as will be seen later, the indications of shortage in phosphoric acid were very similar each year in spite of climatic differences. The work has therefore gained considerably in value from the assurance that the effects are similar under varying climatic conditions.

The pot cultures yielded data under the following heads :—

- (1) Crop yields of seed and straw at harvest.
- (2) Rate of development of crop.
- (3) Composition of crop at harvest.

Full results obtained are shown in the appendix (Tables B, C, and D).

Before we can utilize these figures it is necessary to discuss the accuracy of the results and the accuracy required to make the conclusions certain.

TABLE I.
Showing variations in pot culture crop yields.

	Soil	UNMANURED POTS					NITROGEN POTS					NITROGEN + P ₂ O ₅ POTS				
		1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
1915	{ Nyaunglebin B { Seed Straw	9	8.5	10.5	8	9.0 (0.8)	31	38	36	33	34.5 (2.5)	32	36	37	34	35.0 (1.8)
		13.5	13	12	12	12.6 (0.6)	94	91	81	79	86.0 (6.2)	84	88	90	92	88.5 (2.5)
	{ Dabein B { Seed Straw	11	11	17	18	14.0 (3.2)	30	31	27	30	29.5 (1.2)	38	42	34	40	38.5 (2.5)
		12	20	21	25	19.5 (3.8)	49	38	33	38	39.5 (4.8)	85	94	84	88	88.0 (3.2)
1916	{ Tantabin { Seed Straw	35	31	25	28	30.0 (3.2)	51	59	44	54	52.0 (4.5)	45	50	57	53	51.0 (3.8)
		42	35	30	33	35.0 (3.5)	101	109	76	104	97.5 (10.8)	94	96	111	106	102.0 (6.5)
	{ Insein A { Seed Straw	20	20	20	20	20.0 (0.0)	30	28	30	29	29.0 (0.8)	40	38	39	43	40.0 (1.5)
		27	26	26	30	27.0 (1.2)	46	44	45	50	48.0 (1.8)	100	104	100	100	101.0 (1.5)
1917	{ Thonze { Seed Straw	42	37	36	39	38.5 (2.0)	60	64	60	64	62.0 (2.0)	69	61	60	65	64.0 (3.2)
		50	52	47	51	50.0 (1.5)	104	113	105	104	106.5 (3.2)	101	101	107	110	105.0 (3.8)
	{ Thilawa { Seed Straw	21	26	26	29	25.5 (2.2)	35	27	34	40	34.0 (3.5)	48	50	56	58	53.0 (4.0)
		37	38	38	37	37.5 (0.5)	38	40	45	46	42.0 (3.2)	102	100	105	100	102.0 (1.8)

I. VARIATIONS IN POT CULTURE CROP YIELDS.

Table I gives the actual weighments of the crops of two typical soils for each of the years during which the tests were in progress. Even these figures suffice to show that the year 1915 was decidedly the least favourable for growth. The full Table B brings out this point more conclusively, and indicates that 1917 was somewhat more favourable than 1916.

No attempt has been made to work out in these tables the probable error either of the mean or of the individual pots. It is not feasible when only four pots are available for comparison.

The mean deviation of individual results from the average is however entered in brackets in each case, and, as will be seen, this is quite sufficient to give us confidence in the data.

Amongst all the results obtained there is none so doubtful as the average yield for Dabein B soil unmanured.

Here we have (Table I) from two identically treated pots a yield in one case practically double that of the other. The mean deviation from the average is in this case ± 3.8 or 20 per cent. of the total. This is however quite an exceptional extent of variation. It is worth noticing that even this very serious variation does not approach the differences produced by manuring.

A much more usual case is that illustrated by Tantabin where with nitrogen manure one decidedly low figure and with nitrogen plus phosphoric acid one decidedly high figure are obtained.

The mean deviations in this series are small and obviously quite negligible compared with differences produced by manuring.

The significance of the variations will, however, depend entirely upon the use to which the figures are to be put. It is to show this use that the soils in Table I have been selected.

Neglecting for the present the low yields of 1915 and comparing only the soils of that year, we see that in both cases nitrogen has produced an increase in crop which is far in excess of the mean deviation. The increase with Nyaunglebin is, however, much greater than with Dabein. The effect of nitrogen plus phosphoric acid on Nyaunglebin is scarcely greater than that of nitrogen alone—the difference being of the same order of magnitude as the deviation and therefore not significant.

With Dabein, on the other hand, addition of phosphoric acid leads to a further very marked increase, and this increase being of quite a different order to the mean deviations is undoubtedly significant.

The full data are given in these cases to show that the reliability of the conclusions arrived at cannot be questioned.

Exactly the same point is brought out by the two 1916 and the two 1917 soils.

In all these cases the differences for which we are looking are far greater than the mean experimental error.

A reference to the full Table B shows that practically all the soils examined behave either as one or other of the typical soils just discussed in detail, and that all mean deviations are much less than differences due to manuring.

So long therefore as the crop weighings are utilized solely to differentiate between soils which do and soils which do not give decided increase when phosphoric acid is added to nitrogen manure, we know that the conclusions cannot be vitiated by experimental errors.

It is important to note that similar differences of crop yield are obtained both in favourable and in unfavourable seasons. There is no doubt therefore that seasonal variations do not affect our conclusions regarding soils distinctly rich and distinctly poor in phosphoric acid. The few intermediate samples might be expected to give somewhat divergent results according to the nature of the season, but on the whole there is little evidence in favour of this view.

2. VARIATIONS IN RATE OF DEVELOPMENT.

The rate of development was determined by periodical measurement of the pot plants. The numbers given in Table C are the product of average height of plant multiplied by number of tillers. Each figure given is the average development found in four identically treated pots. The figures are not exact because they do not take into account the thickness of the stems or the amount of foliage. These are, however, generally proportional to the stem development at any given stage of growth, and may therefore without serious error be neglected.

The rate of growth is modified so very greatly by manuring that much cruder figures and even eye estimation alone would serve to bring out the essential points. That this is the case will be seen by referring to the plates showing photographs of typical pots.

Development figures corresponding to the photographs are given below.

TABLE II.

Showing initial development figures corresponding to pot culture photographs.

	Daiku	Tantabin A	Insein A	Pyinbongyi B
Unmanured	575	200	200	400
N alone	1,100	900	300	375
N + P ₂ O ₅	1,248	990	900	1,054

These figures, looked at in conjunction with the photographs, will show that the development data are intended to express in a concrete form such great differences as are evident from eye inspection. Indeed the evidence from the rate of development of the plants is so clear that all the necessary proof could have been given by photographs alone. The full development data given in Table C prove that the photographs are not a collection of exceptionally striking differences.

They are quite typical of the results obtained throughout. We have a number of ether photographs of identical effects with other soils, and there is no question from their evidence also that the development figures are a very fair numerical representation of differences which are striking to the eye.

In this case also climate plays an important part in the rate of development, and as with total crop yields already discussed so here it is impossible to come to any conclusions by comparing rates of development in different seasons.

However if we compare the effect of nitrogen alone and nitrogen plus phosphoric acid, we obtain typical differences between (a) soils which show no acceleration with nitrogen alone and great acceleration with nitrogen plus phosphoric acid, and (b) soils which show very marked acceleration with nitrogen alone and little or no further acceleration with nitrogen plus phosphoric acid. This phenomenon is observed equally clearly in favourable and unfavourable seasons, and may therefore also be used with confidence to differentiate soils.

3. CROP ANALYSIS.

Each figure in Table D gives the phosphoric acid content of the mixed and finely divided straw harvest from four identically treated pots. This precludes the inclusion of any unrepresentative result due to peculiar growth in a single pot. Table D shows that very striking differences exist in phosphoric acid content of straw from different soils. In this case we have not got analyses of individual pots by which the mean deviation and thence the reliability of the figures can be estimated.

We have evidence of another kind however which is quite as convincing and this should be considered here.

When an unmanured soil gives a crop poor in phosphoric acid, it is to be expected that by increasing the crop with nitrogen manuring the crop will become still poorer in phosphoric acid content. This is found to be invariably the case.

Further, if phosphoric acid be added to the nitrogen and the crop thereby be still further increased, it may be expected still to remain somewhat poorer than the average. This is also found to be the case where the soil seriously lacks phosphoric acid.

In no case therefore is the evidence based on less than three analyses each of which represents the mean crop composition of four pots. The same remarks apply to soils which produce straw rich in phosphoric acid.

Straw analyses for a few soils are wanting. This was due to the fact that some plants were attacked by disease and had to be cut out before maturity. The evidence regarding these soils is therefore unavoidably incomplete.

4. TESTS USED IN ESTABLISHING THE PHOSPHORIC REQUIREMENTS OF SOILS.

Soils poor in phosphoric acid may be expected to give increased yields when phosphoric acid is supplied. Very few indeed of the soils tested show this effect. Hmawbi, Hlegu D, Kyauktan, and Thilawa gave slightly increased crops with phosphoric acid. The effect was also just noticeable with Thongwa, Dabein A, and Hlegu C.

It is fairly evident, however, that this is not a complete list of the soils which are poor in phosphoric acid. It does not include some of the very poorest.

There exists therefore a very serious difficulty. This must be considered, but it would be better dealt with when the other evidence has been summarized. This is as follows :—

(a) *Lack of soil phosphoric acid indicated by initial development.*

In Table III some soils which show most characteristic differences in rate of initial development are collected together. (Figures from Table C.) We are not concerned here with the actual rate of growth which must vary with soil and climate, but with the differences produced by nitrogen alone and nitrogen and phosphoric acid on the initial growth.

TABLE III.

Showing rate of initial growth in soils poor and rich in phosphoric acid.

(a) Soils poor in phosphoric acid.

	Dabein A	Dabein B	Ledaung- gan A	Ledaung- gan B	Hlegu C	Kyauktan	Thilawa
Unmanured ...	76	72	60	85	120	240	290
N alone ...	80	80	60	85	120	240	480
N + P ₂ O ₅ ...	480	440	240	240	240	1,050	910

(b) Soils rich in phosphoric acid.

	Nyaungle- bin B	Hmawza	Paungde	Sitkwin	Thonze	Daiku	Tantabin
Unmanured ...	114	500	270	500	530	575	200
N alone ...	550	1,300	880	810	1,090	1,240	900
N + P ₂ O ₅ ...	550	1,300	880	810	1,090	1,180	900

This is undoubtedly the most striking point brought out by the pot cultures. With this criterion the soils can be divided very sharply into two groups, namely, (a) those which give little or no initial increase with nitrogen alone and give an increase when phosphoric acid is supplied in addition, and (b) those which show very marked acceleration with nitrogen alone and practically no further increase when phosphoric acid is added.

There can be no question that according to this test a number of soils are proved to be poor in phosphoric acid and a number well supplied with this ingredient.

The full development Table C shows that all the soils tested can be classified in this way. The figures available for most of the other soils are quite as convincing as those shown above. A few soils give intermediate results. The extent of Table C, however, makes it difficult for the eye to note the striking character of the evidence available.

To show this adequately it was necessary to give a few figures in a smaller table.

(b) Lack of soil phosphoric acid indicated by final straw yields.

Table IV gives the increase in the final straw harvest produced by nitrogen alone and by nitrogen plus phosphoric acid on same typical soils.

In this case nitrogen alone invariably produces a marked increase. In certain soils, however, the addition of phosphoric acid produces a further very pronounced increase, whilst in others nitrogen alone produces practically a maximum crop which is scarcely affected by addition of phosphoric acid.

TABLE IV.
Straw harvest from soils which are respectively poor and rich in P_2O_5 .
 (a) *Soils poor in P_2O_5 .*

	DABEIN A		DABEIN B		LEDAUNGGAN A		LEDAUNGGAN B		HLEGU C		KYAUKTAN		THILAWA	
	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5
Unmanured	17.4	0.085	19.5	0.120	11.2	0.110	20.6	0.081	35.5	0.099	42.5	0.089	37.0	0.049
N alone	35.5	0.033	39.5	0.049	35.0	0.039	35.0	0.029	39.0	0.034	80.5	0.086	42.0	0.027
N + P_2O_5	81.5	0.261	88.0	0.201	68.0	0.210	75.0	0.235	69.0	0.212	112.5	0.260	102.0	0.164

(b) *Soils rich in P_2O_5 .*

	NYAUNGLEBIN B		HMAWZA		PAUNGDE		SITKWIN		THONZE		DAIKU		TANTABIN	
	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5	Straw	% P_2O_5
Unmanured	12.6	0.397	54.0	0.452	33.5	0.357	42.0	0.572	50.0	0.420	61.2	0.277	33.0	0.352
N alone	86.2	0.343	123.0	0.407	95.0	0.435	101.0	0.415	108.5	0.385	125.0	0.385	97.5	0.356
N + P_2O_5	88.5	0.377	126.5	0.473	92.0	0.413	99.0	0.505	105.0	0.439	135.0	0.325	102.0	0.351

Here again there is a very sharp distinction between the soils, and we are able to specify some as decidedly poor in and others definitely well supplied with phosphoric acid.

The full table of crop yields (B) shows that most of the soils tested can be classified in this way.

(c) *Lack of soil phosphoric acid indicated by phosphoric acid in straw harvest.*

These figures are particularly instructive if considered in connection with straw yield. Hence both sets of figures are included in Table IV.

There are two points worth noting in these results :—

(1) When phosphoric acid is low in a crop of unmanured soil it is usually still lower in the nitrogen manured crop. It looks as if the plant had extracted practically all the phosphoric acid it could, and making the crop larger results simply in the formation of more organic matter containing still the same amount of phosphoric acid.

(2) The straw analyses corroborate in a really very convincing manner the conclusions derived from a study of the straw yields.

The full Table D of straw analyses gives similar data for the other soils.

This table should be compared with development Table C. It will be seen that in soils poor in phosphoric acid nitrogen causes no initial increase whatever in growth. The plant at this stage is evidently searching for phosphoric acid. Later it grows at a maximum rate compatible with the phosphoric acid it has obtained, the final crop being much greater than the unmanured plants. The nitrogen manured plants which may be aptly called forced are decidedly abnormal in composition. But Table D shows that even without nitrogen manuring some of the poorest soils produced abnormal plants.

Such plants are very likely to have weaknesses which will manifest themselves in times of drought and during insect attacks. Mr. McKerral, Deputy Director of Agriculture, Southern Circle, Insein, made an observation which bears on this point.

He found that during a favourable season phosphatic manure gave no appreciable increase on Hmawbi farm soil. During an unfavourable season the unmanured plot gave a poor yield owing to insect attack. The adjacent plot manured with phosphoric acid was not appreciably affected and gave a good yield. This result is strikingly corroborated by our pot culture crop analyses.

In the small Tables III and IV (which are amply supported by the full figures of Tables B, C, and D) the evidence regarding lack of phosphoric acid is shown in as obvious and concise a manner as possible. It was necessary to go over this evidence in detail because many of the soils found to be poor in phosphoric acid by these tests gave no appreciable effect with phosphoric acid alone.

The evidence from phosphoric acid manuring alone is therefore quite contradictory. It will be ignored for the present, and we will proceed to classify our soils according to the tests given above.

5. CLASSIFICATION OF SOILS ACCORDING TO PHOSPHORIC ACID REQUIREMENTS.

In Table V all the soils examined have been classified according to each of the three methods described.

TABLE V.

Test	Soils poor in P_2O_5	Intermediate	Soils rich in P_2O_5
1. Effect of Am_2SO_4 with and without P_2O_5 on final yield.	Hmawbi, Kyungon B, Pyinbongyi B, Insein A, Dabein A & B, Pegu B, Ledaunggan A & B, Hlegu C & D, Kyauktan, Thilawa, Thongwa.	Pyinbongyi A	Daiku, Insein B, Tantabin, Nyaunglebin A & B, Pegu A, Hlegu A & B, Kayan, Prome, Thegon, Hmawza, Zigon, Nattalin, Sitkwin, Thonze.
2. Effect of Am_2SO_4 with and without P_2O_5 on initial development.	Hmawbi, Yedashe B, Kyungon A & B, Pyinbongyi A & B, Insein A, Dabein A & B, Pegu B, Ledaunggan A & B, Hlegu C & D, Kyauktan, Thilawa, Thongwa.	Yedashe A, Nyaunglebin A.	Daiku, Insein B, Tantabin, Nyaunglebin B, Pegu A, Hlegu A & B, Kayan, Prome, Thegon, Hmawza, Zigon, Nattalin, Sitkwin, Thonze.
3. Chemical analysis of crop.	Kyungon B, Pyinbongyi B, Insein A & B, Dabein A & B, Ledaunggan A & B, Hlegu C & D, Kyauktan, Thilawa.	Pyinbongyi A, Pegu B, Thongwa.	Daiku, Tantabin, Nyaunglebin A & B, Pegu A, Hlegu A & B, Kayan, Prome, Thegon, Hmawza, Zigon, Nattalin, Sitkwin, Thonze.

With very few exceptions all three tests lead to identical conclusions. This in itself is a proof that the tests are satisfactory. Insein B is a striking exception. This soil produces large crops with nitrogen alone, shows little or no further increase with phosphoric acid, and would naturally be classed as a soil rich in phosphoric acid. The straw analysis, however, indicates serious poverty. A similar result has been obtained before with another sandy soil. In consequence of the very poor straw the soil must be classed as poor. Pyinbongyi A gives intermediate results in two cases although its content of

phosphoric acid is low. At all events it does not approach the reactions of a rich soil. Nyaunglebin A shows slight weakness but on the whole it is associated closely with the rich soils.

6. RELATION BETWEEN CULTURAL TESTS AND THE PHOSPHORIC ACID CONTENT OF SOILS.

To bring out this relationship, the summary of information derived from pot cultures (Table V) must be considered in conjunction with soil analysis results. For this purpose Table VI has been prepared.

TABLE VI.

Serial No.	Name of soil	Soluble silica	Nitrogen	Total P ₂ O ₅	Available P ₂ O ₅	Pot cultures
1	Hlegu A	20.96	0.128	0.07	0.0044	Rich
2	Nyaunglebin A	18.97	0.116	0.08	0.0070	"
3	Yedashe A	17.91	0.099	0.04	0.0048	Poor
4	Ledaunggan A	17.05	0.128	0.03	0.0017	"
5	Paungde	16.79	0.131	0.10	0.0150	Rich
6	Zigon	16.39	0.139	0.08	0.0080	"
7	Daiku	16.41	0.113	0.07	0.0187	"
8	Ledaunggan B	16.15	0.133	0.04	0.0019	Poor
9	Nyaunglebin B	15.97	0.079	0.11	0.0213	Rich
10	Thegon	15.32	0.142	0.11	0.0279	"
11	Prome	15.40	0.078	0.07	0.0036	"
12	Hmawbi	15.26	0.072	0.03	0.0029	Poor
13	Nattalin	15.10	0.168	0.13	0.0373	Rich
14	Dabein A	12.99	0.107	0.03	0.0011	Poor
15	Insein A	12.45	0.105	0.02	0.0009	"
16	Hlegu D	12.47	0.116	0.02	0.0007	"
17	Pyinbongyi A	11.94	0.089	0.03	0.0057	"
18	Thilawa	11.62	0.116	0.03	0.0023	"
19	Dabein B	10.63	0.084	0.02	0.0010	"
20	Hlegu B	10.33	0.076	0.05	0.0045	Rich
21	Thongwa	10.24	0.119	0.04	0.0057	Poor
22	Sitkwin	10.03	0.076	0.08	0.0304	Rich
23	Kyauktan	9.95	0.105	0.03	0.0012	Poor
24	Thonze	9.38	0.081	0.06	0.0134	Rich
25	Hmawza	8.94	0.076	0.39	0.2360	"
26	Kayan	8.76	0.081	0.05	0.0189	"
27	Tantabin B	8.51	0.057	0.09	0.0468	"
28	Tantabin A	8.38	0.051	0.09	0.0449	"
29	Yedashe B	8.32	0.053	0.01	0.0012	Poor
30	Pegu B	7.99	0.061	0.02	0.0030	"
31	Pegu A	7.07	0.072	0.03	0.0039	Rich
32	Kyungon B	6.56	0.065	0.01	0.0009	Poor
33	Hlegu C	6.25	0.087	0.02	0.0013	"
34	Kyungon A	6.03	0.051	0.01	0.0009	"
35	Pyinbongyi B	5.51	0.068	0.02	0.0020	"
36	Insein B	3.91	0.104	0.02	0.0016	"

This table shows in the first place that with Lower Burma soils the figures for total phosphoric acid are on the whole better than the availability figures as an index of lack of phosphoric acid. For example, amongst the first three soils on the list the availability figures for Yedashe and Hlegu A are the same.

The figures for total phosphoric acid of these two soils are very different and lead one to expect Yedashe to be the poorer. This conclusion is corroborated by the culture test.

Again No. 11 Prome compared with No. 17 by available figure should be poor. Pot tests show that it is not poor, and here again the figure for total phosphoric acid is the better index.

Hlegu B (No. 20) and Thongwa (No. 21) should according to availability figure be about the same with perhaps a slight advantage in favour of Thongwa. Pot cultures showed that Hlegu B was richer than Thongwa, and this agrees with the figures for total phosphoric acid.

It should be noted that in each of these cases we are comparing soils of similar texture, and that therefore the conclusions are better justified than they otherwise would be.

The data can be used further to estimate the amount of soil phosphoric acid which may be considered sufficient.

Amongst the denser soils, Nos. 3 and 8, containing 0.04 per cent. phosphoric acid, show lack of phosphoric acid. The next higher figures are Nos. 1 and 7 with 0.07 per cent. These show no lack of phosphoric acid; No. 2 containing 0.08 per cent., however, showed some signs of weakness. Soils of this kind must therefore contain 0.07 or 0.08 per cent. phosphoric acid to be satisfactory.

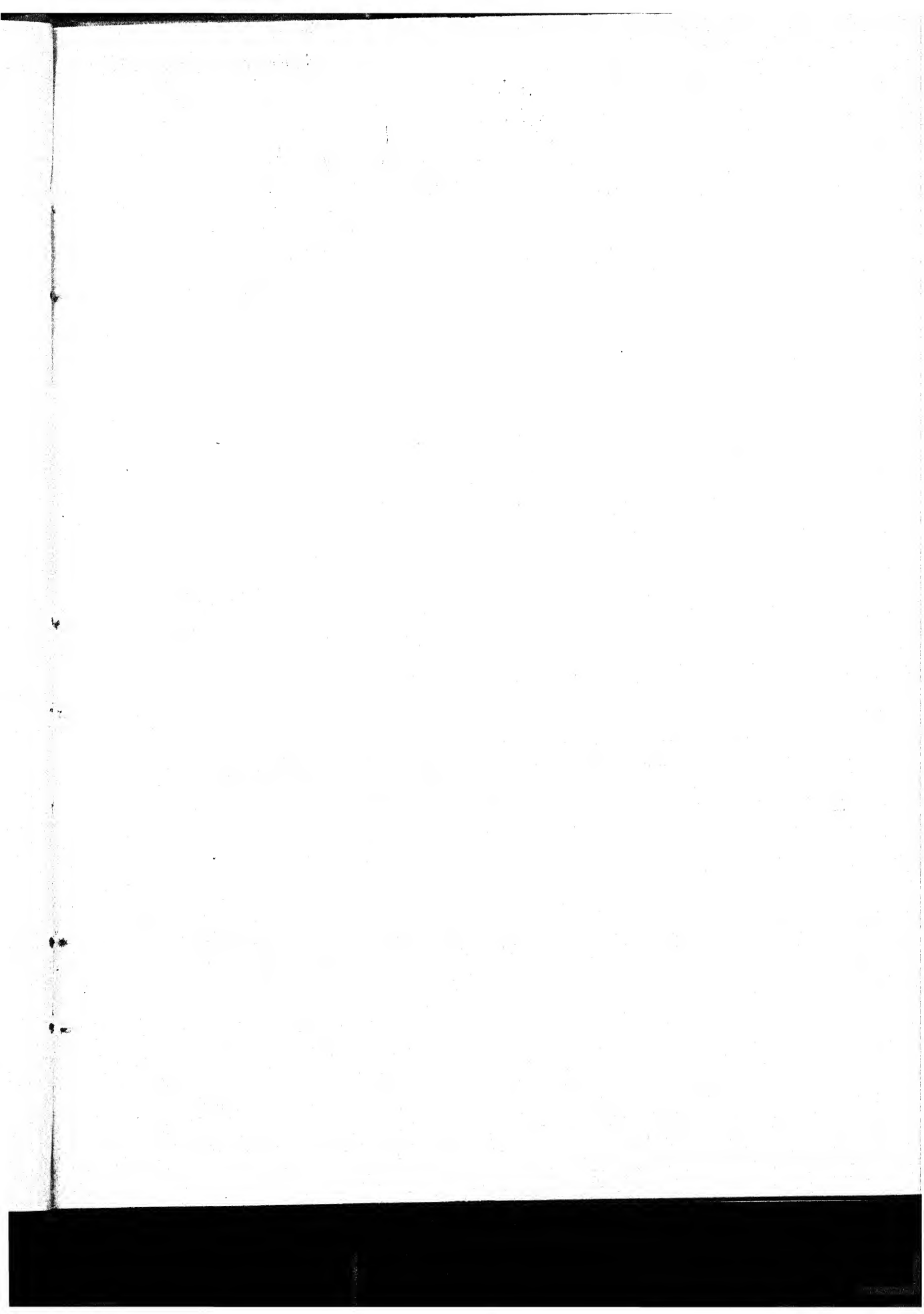
In the second group there are no soils near the limit and an estimate cannot be made.

In the third group, two soils, Nos. 20 and 26, containing 0.05 per cent., are found to be rich, whilst one containing 0.04 per cent. is poor.

In the last group the evidence is somewhat slender. These soils should probably contain not less than 0.03 per cent. phosphoric acid to give satisfactory crops.

We have not got a perfect sequence of figures in any case to come to a final conclusion, but taking all the evidence together it appears that the denser soils require a higher percentage of phosphoric acid than the more open soils.

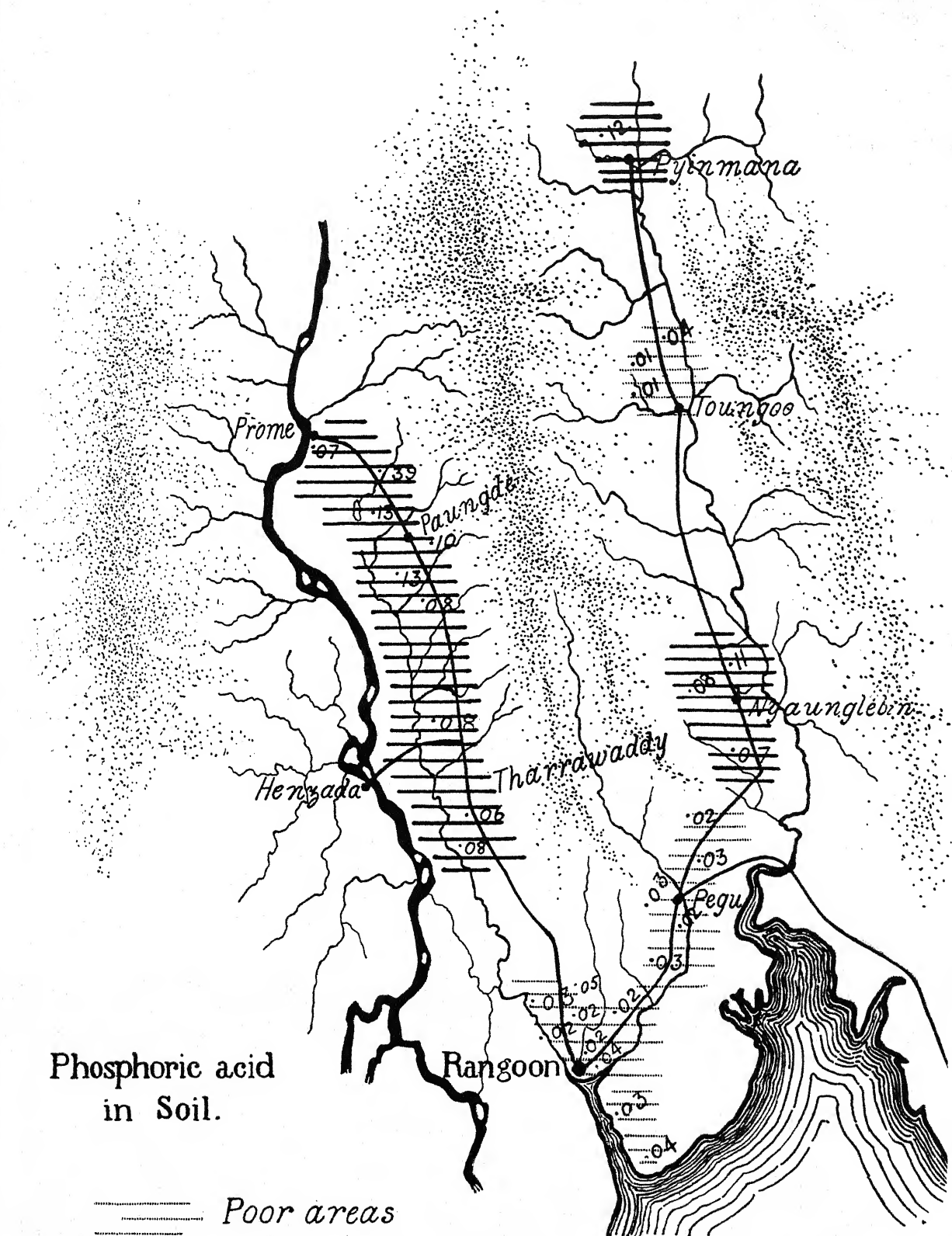
For the denser soils probably 0.07 per cent. is the lowest safe figure. For sandy loams 0.05 per cent. is seen to be sufficient, whilst very sandy soils may be able to produce full crops with a still smaller supply. Insein B with 0.02 per cent. phosphoric acid is able to produce a full crop, but the crop is decidedly deficient in phosphoric acid. The phosphoric acid content



Phosphoric acid
in Soil.

— — — — — Poor areas

===== Rich areas



required to produce satisfactory paddy crops even in the case of heavy soils (which appear to demand decidedly more than the lighter soils) is found to be somewhat lower than the amount usually considered necessary. The limiting quantities of phosphoric acid here given refer to pot cultures. The limit for field cultures might be slightly different but we can scarcely conceive that they would be higher.

Mr. W. A. Davis (*The Agricultural Journal of India*, Science Congress Number, 1917) gives available phosphoric acid data from typical calcareous Gangetic soils. Some of these figures are extremely low even compared with our low figures.

The total phosphoric acid of these soils is however not given, and therefore a true comparison with our results cannot be made.

Rawson (also quoted in the same paper) gives total and available phosphoric acid figures for some Gangetic soils, which, according to the standards just established for the Lower Burma soils, would be considered decidedly high. Experimental manuring has, however, shown that the soils are deficient in phosphoric acid. These results prove that the Lower Burma soils require less phosphoric acid to produce satisfactory crops than is needed by the Gangetic soils.

7. DISTRIBUTION OF PHOSPHORIC ACID IN THE SOILS OF LOWER BURMA.

With the aid of Table VI, a soil map has been prepared showing distribution of soils rich and poor in phosphoric acid respectively. We see from this map that there is a large area of soils rich in phosphoric acid in the Hlaing valley along the Rangoon-Prome line.

Another rich area occurs between Nyaunglebin and Daiku. Its extent has not been determined.

Much further north we strike a rich soil at Pyinmana, but between these two last areas there lies a region of poor soils in the neighbourhood of Toungoo.

The most extensive area of poor soils lies within Pegu, Hanthawaddy and Insein districts.

8. SOIL NITROGEN SUPPLY.

To elucidate the contradictory results of manuring with super alone, some points regarding nitrogen supply must be considered.

TABLE VII.

Showing association of high nitrogen with low phosphoric acid.

Serial No.	Name of soil	Nitrogen	Phosphoric acid	Class
1	Dabein B	0.084	0.02	Poor
2	Hlegu B	0.076	0.05	Rich
3	Thongwa	0.119	0.04	Poor
4	Sitkwin	0.076	0.08	Rich
5	Kyauktan	0.105	0.03	Poor
6	Thonze	0.081	0.06	Rich
7	Hlegu D	0.116	0.02	Poor
8	Tantabin	0.057	0.09	Rich

The above table shows that in certain cases low phosphoric acid is associated with high nitrogen. We have a collection of soils which are alternately poor and rich in phosphoric acid content. Some additional less typical soils will be seen in the full Table A. The peculiarity here indicated is by no means universal amongst the Lower Burma soils, but the number of cases in which it is seen is sufficient to be striking.

The point to which attention is called is that the soils relatively rich in phosphoric acid are deficient in nitrogen, whilst those which are poor in phosphoric acid are richer in nitrogen.

This indicates certainly that with soils poor in phosphoric acid the nitrogen is not so completely utilized.

Such a result must be due to one or more of the following causes :—

- (1) Poor plant growth through lack of phosphoric acid.
- (2) More resistant character of the organic matter in these soils.
- (3) Biological environment unfavourable to disintegration of organic matter.

An important field of enquiry is indicated by this phenomenon.

The addition of phosphatic manures to these soils has been shown in our pot cultures to have no immediate effect on ammonification. This is an important result from a practical point of view. There can be little doubt, however, from the evidence of the richer soils, that in time addition of phosphoric acid would improve the ammonification in the poorer soils.

Before leaving this table it is perhaps desirable to point out that the pot cultures showed nitrogen to be effective on the even numbers which are low in nitrogen and not effective on the odd numbers which are richer in nitrogen. It might be assumed from this that the pot cultures merely showed lack of nitrogen and have nothing to do with the phosphatic requirements.

That this is quite wrong is proved by the following evidence:—

(a) The soils rich in phosphoric acid whether they be poor or rich in nitrogen are found to behave identically with nitrogen manuring.

(b) The initial effect of nitrogen in the soils of Table VI is not inversely proportional to the amount of nitrogen they contain, but is zero when phosphoric acid is lacking and is perfect when phosphoric acid is sufficient.

(c) The plants grown on poor soils are seriously deficient in phosphoric acid.

(d) The powerful effect of adding phosphoric acid to nitrogen in the case of soils poor in phosphoric acid and the corresponding absence of effect with soils well supplied with phosphoric acid.

Considering the nitrogen figures of all the soils we see that a few are decidedly poor. Most are moderately well supplied and some may be considered rich in nitrogen. The soil nitrogen is made available to the plant through biochemical processes which are certainly not very effective in our pot cultures, although one month was allowed for the pots to develop their normal bacterial flora before the plants were put in, and the previous treatment of drying and crushing to which these soils were submitted has been shown in a large number of experiments carried out in the laboratory here to improve ammonification.

The inadequacy of available nitrogen in these soils is shown by the great crop increases produced by nitrogen manuring, especially if shortage of phosphoric acid is at the same time made good.

This lack of available nitrogen is doubtless the explanation of the negative and contradictory results with superphosphate manuring alone.

The great advantage of ammonium sulphate in this enquiry will now be evident. By it we ensure a supply of nitrogen quite independent of biochemical activity, and the phosphoric acid of the soil or manure can then come into operation.

Without at present attempting to assign a reason for the fact, we have to conclude that all these soils, more especially those poor in phosphoric acid, are not liberating nitrogen plant food readily.

The pot cultures have shown that without readily available nitrogen phosphatic manuring is useless.

The soils are at least moderately well supplied with nitrogen, and it would suffice if only it could be made more available. There is one method of

making the soil nitrogen available for paddy, and that is by converting it into green manure.

This actually happens every year all over Lower Burma. Before the fields can be ploughed they are covered with vegetation. If this green manure is sufficient in quantity the poor soils may still be able to give immediate effects with phosphatic manuring. The question is of considerable importance to the agriculture of the province.

III. SUMMARY.

(1) By using ammonium sulphate as a source of nitrogen which is not dependent upon the biochemical activity of the soil, and thus removing a serious complication, pot cultures have yielded striking figures which clearly differentiate soils lacking in phosphoric acid from those which are well supplied with phosphoric acid.

(2) The phosphoric acid content necessary to produce satisfactory crops has been shown to be somewhat lower than the amount usually considered necessary.

(3) The lack of phosphoric acid is by no means general all over Lower Burma. It is serious only within definite areas. The available phosphate supplies of the province will therefore meet the want more easily than it was feared might be the case.

(4) The soil nitrogen in these soils is far from readily available. This seems to be more particularly true of the soils poor in phosphoric acid.

The lack of available nitrogen is so serious that phosphoric acid manuring cannot increase crop yields on soils poor in phosphoric acid.

(5) It is possible that the vegetation produced during the early rains is sufficient to act as a green manure, thus making the nitrogen more readily available. If so, phosphoric acid manuring will give immediate crop increase on such soils. This question seems to be of special importance.

APPENDIX.

TABLE A.

Soil analyses.

1915.

Name of soil	Vedashe A	Vedashe B	Kyungon A	Kyungon B	Daiiku	Pyinbongyi A	Pyinbongyi B	Insein A	Insein B	Tantabin A	Tantabin B
Insoluble residue	54.30	81.66	81.37	84.20	58.10	71.00	84.65	69.48	89.88	77.92	77.24
Soluble silica	17.91	8.32	6.08	6.56	16.41	11.94	5.51	12.45	3.91	8.38	8.51
Ferric oxide (Fe_2O_3)	5.30	1.85	1.81	1.94	5.66	2.42	1.63	3.21	0.55	3.79	3.65
Alumina (Al_2O_3)	13.46	4.67	4.65	4.11	11.43	8.59	4.51	8.50	2.18	5.93	5.88
Lime (CaO)	0.35	0.14	0.12	0.12	0.20	0.06	0.05	0.07	0.04	0.30	0.28
Magnesia (MgO)	0.50	0.17	0.09	0.09	0.40	0.08	0.05	0.15	0.03	0.35	0.46
Potash (K_2O)	0.76	0.37	0.24	0.21	0.80	0.41	0.24	0.60	0.14	0.31	0.46
Soda (Na_2O)	0.30	0.15	0.18	0.20	0.43	0.22	0.18	0.29	0.19	0.26	0.29
Sulphuric acid (SO_3)	0.06	0.04	0.03	0.05	0.06	0.05	0.07	0.10	0.03	0.06	0.07
Phosphoric acid (P_2O_5)	0.01	0.01	0.01	0.01	0.07	0.03	0.02	0.02	0.02	0.09	0.09
Carbon-dioxide (CO_2)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Organic matter + Combined water	7.02	2.62	2.42	2.51	6.43	5.19	3.08	5.57	3.02	2.61	3.06
Organic carbon											
Organic nitrogen	0.0992	0.0525	0.0514	0.0654	0.1132	0.0887	0.0677	0.1051	0.1037	0.0514	0.0573
Available phosphoric acid	0.0048	0.0012	0.0009	0.0009	0.0182	0.0057	0.0020	0.0009	0.0016	0.0449	0.0468
Available potash	0.0352	0.0209	0.0066	0.0221	0.0329	0.0161	0.0135	0.0124	0.0134	0.0201	0.0209

TABLE A—continued.

1916.

Name of soil	Nyaunglebin A	Nyaunglebin B	Ledaunggan A	Ledaunggan B	Pegu A	Pegu B	Dabein A	Dabein B	Hlegu A	Hlegu B	Hlegu C	Hlegu D
Insoluble residue	57.94	58.14	52.36	51.88	83.92	79.25	66.85	71.86	49.66	75.04	85.35	71.90
Soluble silica	18.97	15.97	17.05	16.15	7.07	7.99	12.99	10.63	20.96	10.33	6.25	12.47
Ferric oxide (Fe_2O_3)	7.63	6.22	7.06	6.91	1.26	2.30	4.98	4.15	4.94	4.23	0.63	1.12
Alumina (Al_2O_3)	14.10	11.44	13.05	14.33	4.28	6.31	9.64	7.84	14.06	6.32	4.53	8.51
Lime (CaO)	0.25	0.25	0.17	0.26	0.06	0.13	0.16	0.18	0.25	0.21	0.07	0.08
Magnesia (MgO)	1.25	0.57	0.77	0.80	0.05	0.07	0.08	0.11	0.49	0.57	0.04	0.11
Potash (K_2O)	0.96	0.73	0.82	1.03	0.23	0.34	0.51	0.51	0.74	0.24	0.17	0.34
Soda (Na_2O)	0.35	0.27	0.31	0.39	0.16	0.23	0.28	0.19	0.52	0.29	0.16	0.21
Sulphuric acid (SO_3)	0.05	0.04	0.05	0.07	0.05	0.07	0.06	0.05	0.08	0.04	0.04	0.05
Phosphoric acid (P_2O_5)	0.08	0.11	0.03	0.04	0.03	0.02	0.03	0.02	0.07	0.05	0.02	0.02
Carbon-dioxide (CO_2)	0.10	0.08	0.09	0.04	0.03	0.06	0.05	0.02	0.08	0.06	0.04	0.03
Organic matter + Combined water	8.32	6.18	8.24	8.10	2.86	3.23	4.37	4.44	8.15	2.62	2.70	5.16
Organic carbon	0.6103	0.2853	0.7360	1.4600	0.7370	0.7160	0.7700	0.8730	1.1607	0.7110	0.8800	1.3836
Organic nitrogen	0.1156	0.0794	0.1284	0.1331	0.0724	0.0807	0.1074	0.0841	0.1278	0.0755	0.0871	0.1162
Available phosphoric acid	0.0073	0.0213	0.0017	0.0019	0.0097	0.0030	0.0011	0.0010	0.0044	0.0045	0.0013	0.0007
Available potash	0.0147	0.0375	0.0070	0.0066	0.0039	0.0112	0.0139	0.0155	0.0178	0.0201	0.0128	0.0064

TABLE A—concluded.

1917.

Name of soil	Nattalin	Zigon	Sitkwin	Thonze	Promé	Hmawza	Thegon	Pannge	Kyauktan	Thongwa	Thilawa	Kayan
Insoluble residue	60.32	55.19	68.84	75.51	58.46	78.73	55.80	51.99	73.00	69.99	64.75	75.14
Soluble silica	15.10	16.39	10.03	9.38	15.40	8.91	15.32	16.79	9.95	10.24	11.62	8.76
Ferric oxide (Fe_2O_3)	7.27	7.82	4.55	4.33	6.61	2.60	7.03	7.70	4.07	5.18	6.03	3.36
Alumina (Al_2O_3)	9.95	11.90	6.30	6.15	11.10	4.79	11.45	13.48	7.21	8.36	9.76	7.02
Lime (CaO)	0.39	0.23	0.24	0.20	0.26	0.15	0.35	0.55	0.17	0.22	0.12	0.26
Magnesia (MgO)	1.12	1.05	0.94	0.78	0.80	0.07	1.09	0.13	0.29	0.30	0.17	0.61
Potash (K_2O)	0.65	0.96	0.46	0.45	0.91	0.36	0.93	1.02	0.39	0.39	0.41	0.42
Soda (Na_2O)	0.10	0.04	0.05	0.06	0.77	0.45	0.53	0.58	0.16	0.14	0.12	0.22
Salphuric acid (SO_3)	0.08	0.05	0.03	0.05	0.06	0.07	0.07	0.08	0.07	0.05	0.10	0.06
Phosphoric acid (P_2O_5)	0.13	0.08	0.08	0.06	0.07	0.39	0.11	0.10	0.03	0.04	0.03	0.05
Carbon-dioxide (CO_2)	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.00	0.01
Organic matter + Combined water	4.88	6.27	8.46	3.01	5.55	3.43	7.30	7.56	4.65	5.18	6.89	4.06
Organic carbon	1.4471	1.2147	0.8149	0.7504	0.6474	0.7549	1.2992	1.0374	1.1830	1.2049	1.8502	0.8111
Organic nitrogen	0.1684	0.1394	0.0755	0.0813	0.0784	0.0755	0.1423	0.1307	0.1045	0.1191	0.1162	0.0813
Available phosphoric acid	0.0373	0.0083	0.0304	0.0134	0.0036	0.2365	0.0279	0.0150	0.0012	0.0057	0.0023	0.0189
Available potash	0.0108	0.0093	0.0058	0.0077	0.0128	0.0100	0.0101	0.0070	0.0101	0.0070	0.0070	0.0077

TABLE B.
Showing pot culture crop yields.

Year	Soil	AVERAGE WEIGHT OF SEEDS				AVERAGE WEIGHT OF STRAW			
		Blank	Super-phosphate	Am ₂ SO ₄	Am ₂ SO ₄ + Super-phosphate	Blank	Super-phosphate	Am ₂ SO ₄	Am ₂ SO ₄ + Super-phosphate
1915	Kyungon B	29 7(1.2)	.....	39 0(2.5)	42 0(4.0)	40 0(2.0)	.....	71 0(3.8)	104 0(11.0)
	Dalku	33 1(3.4)	.....	54 2(3.7)	57 0(4.5)	61 2(4.5)	.....	125 0(7.8)	135 0(14.8)
	Pyinbongyi A	51 8(2.8)	.....	63 2(3.2)	62 2(2.6)	78 5(2.1)	.....	108 5(8.5)	112 0(6.2)
	Pyinbongyi B	35 7(1.0)	.....	40 0(1.2)	51 5(4.2)	57 5(1.6)	.....	81 0(3.8)	114 0(1.5)
	Insein A	20 7(1.5)	.....	29 2(0.7)	40 0(1.5)	27 5(1.5)	.....	46 0(1.8)	101 0(1.0)
	Insein B	44 2(3.2)	.....	55 0(2.2)	49 0(7.8)	96 0(1.9)	.....	116 0(10.2)	115 5(8.2)
	Tantabin A	20 5(3.1)	.....	52 0(4.5)	51 2(3.8)	33 0(3.0)	.....	97 5(10.8)	102 0(6.3)
	Nyaunglebin A	6 0(1.2)	6 0(0.4)	30 0(2.4)	32 0(2.6)	10 0(0.8)	10 0(0.25)	74 0(1.25)	83 0(3.25)
	Nyaunglebin B	9 0(0.8)	8 4(0.4)	34 6(2.6)	35 0(1.8)	12 6(0.6)	12 6(1.4)	86 0(6.2)	88 5(2.5)
	Dabin A	13 5(1.5)	10 6(1.6)	29 4(3.9)	33 0(1.9)	17 4(1.1)	14 0(1.5)	35 5(5.8)	81 5(6.0)
1916	Dabin B	14 3(3.3)	12 5(0.25)	29 6(1.3)	39 0(2.2)	19 5(3.8)	16 0(0.9)	39 5(4.8)	88 0(3.2)
	Pegu A	21 0(1.8)	23 0(1.9)	38 0(1.6)	39 6(2.6)	30 5(2.0)	34 0(2.0)	71 0(1.8)	74 5(5.2)
	Pegu B	20 6(2.1)	20 4(1.1)	43 0(3.6)	39 0(2.8)	25 0(3.2)	26 5(1.8)	61 0(2.5)	89 5(6.5)
	Ledaunggan A	7 6(1.1)	7 0(0.6)	30 0(2.2)	35 4(1.7)	11 0(1.2)	9 6(0.9)	35 0(0.0)	68 0(3.0)
	Ledaunggan B	12 4(1.4)	12 6(0.9)	30 0(2.0)	35 0(1.5)	20 6(2.2)	21 0(2.5)	33 0(4.0)	75 0(5.75)
	Hlegu A	10 6(2.0)	8 6(1.1)	19 5(7.8)	34 0(7.6)	16 0(2.8)	13 5(1.5)	79 0(4.8)	84 0(4.8)
	Hlegu B	22 0(1.8)	21 6(1.9)	50 0(0.8)	45 0(1.6)	39 5(2.5)	42 0(2.8)	86 5(3.5)	91 5(2.0)
	Hlegu C	17 0(1.8)	16 4(1.1)	27 0(2.8)	42 5(3.0)	35 5(3.0)	42 0(2.8)	39 0(4.8)	69 0(6.5)
	Hlegu D	22 0(1.6)	28 0(1.2)	32 0(7.8)	43 0(3.8)	37 0(3.5)	45 5(1.5)	61 5(2.2)	75 0(2.2)
	Kyauktan	30 0(1.8)	35 5(1.2)	52 0(4.5)	60 5(2.2)	42 5(1.5)	53 5(2.0)	80 5(7.2)	112 5(2.5)
1917	Thilawa	25 5(2.2)	39 0(1.5)	36 0(4.0)	54 0(3.8)	37 0(0.5)	58 0(1.2)	42 0(2.8)	102 0(1.8)
	Thongwa	32 0(1.8)	33 0(2.5)	59 0(6.8)	53 0(2.8)	45 5(3.0)	52 0(2.8)	95 0(5.0)	106 0(6.5)
	Kayan	30 5(2.2)	30 0(3.2)	51 0(2.5)	50 0(2.2)	44 0(2.0)	45 5(2.8)	107 5(3.0)	98 0(5.2)
	Prome	15 0(2.2)	18 5(2.5)	41 0(1.2)	42 0(0.5)	21 0(2.8)	26 0(1.8)	89 0(4.8)	92 0(3.8)
	Hmawza	44 0(4.2)	48 0(1.8)	73 0(7.2)	70 5(5.0)	66 0(6.2)	73 0(4.0)	137 0(7.2)	127 0(4.8)
	Paungde	43 0(3.8)	45 5(0.8)	68 0(0.8)	69 0(4.0)	54 0(6.2)	63 0(2.2)	123 0(4.8)	126 5(8.0)
	Zigon	23 0(3.8)	23 0(1.8)	45 0(2.8)	39 0(4.0)	33 5(3.5)	33 0(2.0)	95 0(4.5)	92 0(5.5)
	Nattalin	48 0(2.5)	26 0(1.0)	48 5	44 0	41 0(2.0)	39 0(0.75)	71 0	68 5
	Sitkwin	28 0(3.5)	47 5(7.0)	70 0(2.8)	63 0(2.8)	75 0(4.8)	79 0(6.0)	143 5(4.0)	142 5(2.8)
	Thonze	32 0(1.2)	32 0(1.2)	53 0(4.8)	59 0(1.5)	42 0(2.5)	42 0(1.0)	101 0(3.5)	99 0(1.8)



TABLE C.

Showing initial development of paddy in pot cultures.

Year	Name of soil			Blank	Super-phosphate	Am ₂ SO ₄	Am ₂ SO ₄ + Super-phosphate
1915	Yedashe A	...	...	350	.....	754	1,075
	Yedashe B	...	...	300	.....	300	910
	Kyungon A	...	...	237	.....	250	850
	Kyungon B	...	...	300	.....	350	850
	Daik-u	...	...	575	.....	1,100	1,248
	Pyinbongyi A	...	...	600	.....	600	900
	Pyinbongyi B	...	...	400	.....	375	1,054
	Insein A	...	...	200	.....	300	900
	Insein B	...	...	1,215	.....	1,215	1,215
	Tantabin A	...	...	200	.....	900	900
	Tantabin B	...	...	468	.....	1,004	1,000
1916	Nyaunglebin A	...	...	84	80	294	528
	Nyaunglebin B	...	...	114	100	551	550
	Dabein A	...	...	76	123	80	484
	Dabein B	...	...	72	80	80	441
	Pegu A	...	...	180	210	355	400
	Pegu B	...	...	68	69	70	380
	Ledaunggan A	...	...	64	64	64	240
	Ledaunggan B	...	...	85	85	85	242
	Hlegu A	...	...	90	90	390	320
	Hlegu B	...	...	300	300	383	400
	Hlegu C	...	...	120	190	120	238
	Hlegu D	...	...	120	280	162	216
	Kyauktan	...	...	242	504	242	1,053
1917	Thilawa	...	...	294	483	483	910
	Thongwa	...	...	529	625	650	1,146
	Kayan	...	...	529	598	944	1,146
	Prome	...	...	231	231	725	884
	Thegon	...	...	792	792	1,320	1,218
	Hmawza	...	...	506	300	1,334	1,334
	Paungde	...	...	266	266	884	884
	Zigon	...	...	462	462	900	1,000
	Nattalin	...	...	696	696	1,283	1,595
	Sitkwin	...	...	504	504	814	814
	Thonze	...	...	529	529	1,092	1,092

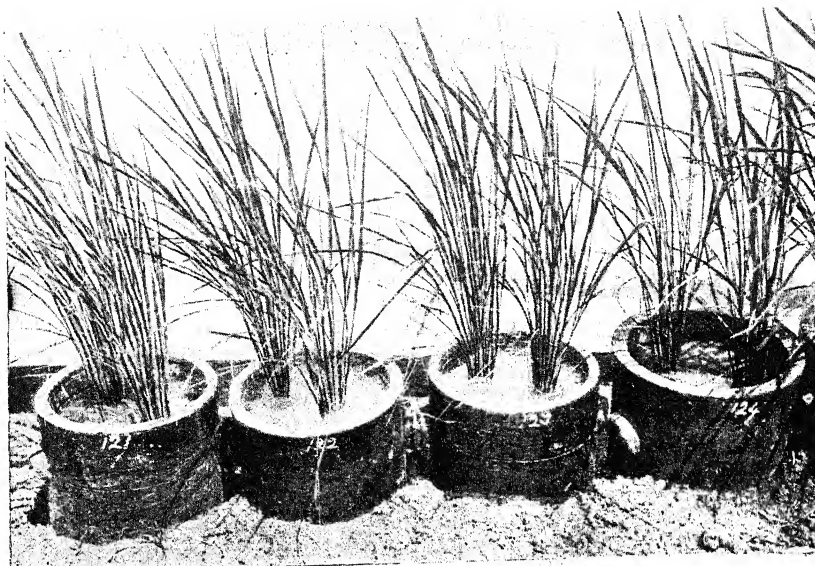
NOTE.—This table shows development attained 4 weeks after transplanting. Measurements were made and figures are available for development at regular intervals throughout the period of growth. The inclusion of all these figures would have made the table very cumbersome and they have therefore been excluded. Some idea of the notable difference which occurred during further development may be seen by comparing this table with Table B giving final crop yields.

TABLE D.
 P_2O_5 in straw.

Year	Name of soil	Blank	Super-phosphate	Am_2SO_4	$Am_2SO_4 +$ Super-phosphate
1915	Kyungon B	0.0427	.....	0.0376	0.2035
	Daiku	0.2770	.....	0.3351	0.3249
	Pyinbongyi A	0.2616	.....	0.1419	0.2685
	Pyinbongyi B	0.0479	.....	0.0479	0.2086
	Insein A	0.0239	.....	0.0239	0.1915
	Insein B	0.1864	.....	0.1590	0.3659
	Tantabin A	0.3523	.....	0.3557	0.3506
1916	Nyaunglebin A	0.2982	0.3386	0.3502	0.3186
	Nyaunglebin B	0.3972	0.3907	0.3437	0.3774
	Dabein A	0.0850	0.3527	0.0330	0.2609
	Dabein B	0.1200	0.3442	0.0486	0.2009
	Pegu A	0.4810	0.4754	0.4229	0.4053
	Pegu B	0.3749	0.4116	0.1598	0.3603
	Ledaunggan A	0.1101	0.2994	0.0393	0.2095
	Ledaunggan B	0.0809	0.3134	0.0291	0.2346
	Hlegu A	0.3805	0.3531	0.5198	0.4634
	Hlegu B	0.5327	0.4857	0.4438	0.4651
	Hlegu C	0.0992	0.4620	0.0842	0.2117
	Hlegu D	0.0641	0.4147	0.0530	0.1402
1917	Kyauktan	0.0887	0.3388	0.0661	0.2604
	Thilawa	0.0486	0.2308	0.0271	0.1641
	Thongwa	0.3260	0.3175	0.1803	0.3667
	Kayan	0.4226	0.3474	0.2986	0.4603
	Prome	0.3218	0.3069	0.3448	0.3693
	Thegon	0.4113	0.3979	0.4132	0.4115
	Hmawza	0.4518	0.5035	0.4074	0.4727
	Paungde	0.3569	0.3964	0.4347	0.4134
	Zigon	0.3508	0.3416	0.4597	0.5093
	Nattalin	0.4077	0.4413	0.4258	0.3973
	Sitkwin	0.5719	0.5051	0.4151	0.5051
	Thonze	0.4198	0.4665	0.3846	0.4393

DAIKU SOIL.

NO MANURE



NITROGEN

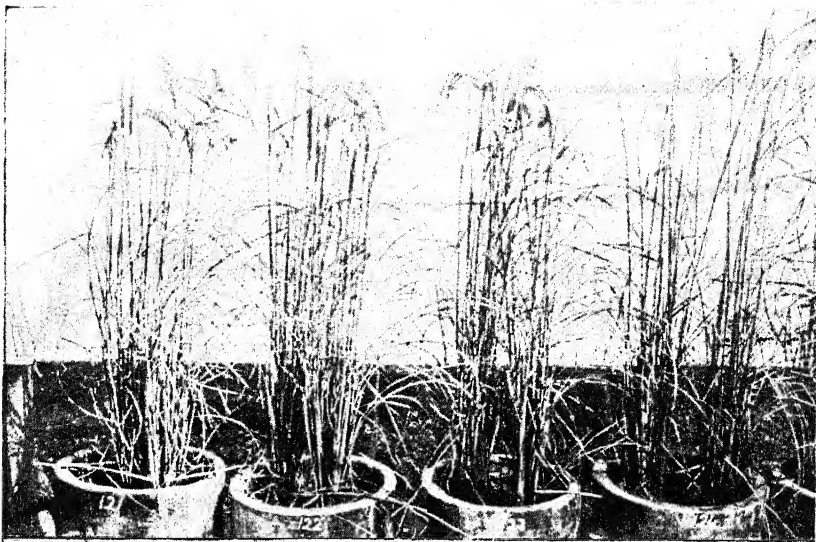


PHOSPHORUS AND NITROGEN



DAIKU SOIL.

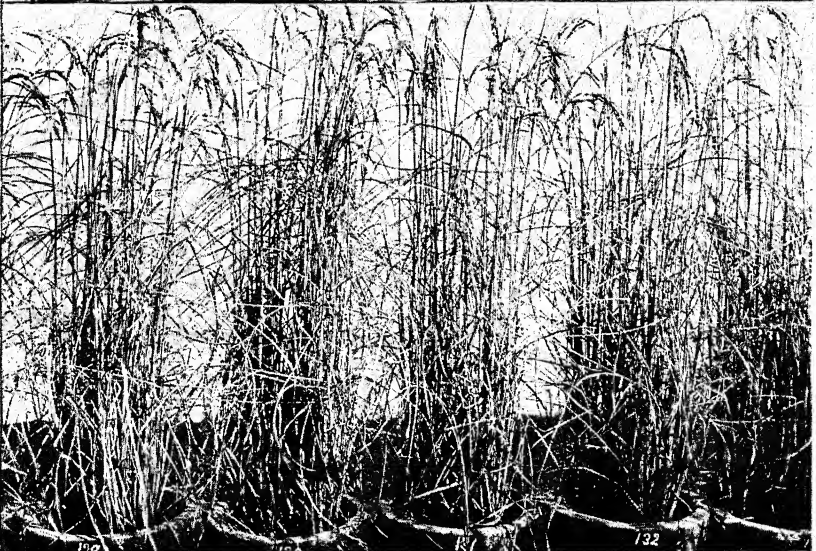
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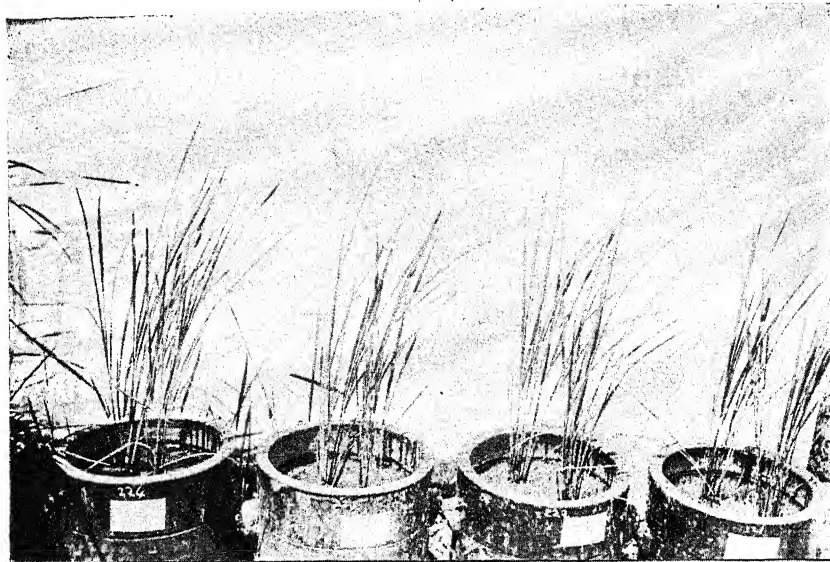
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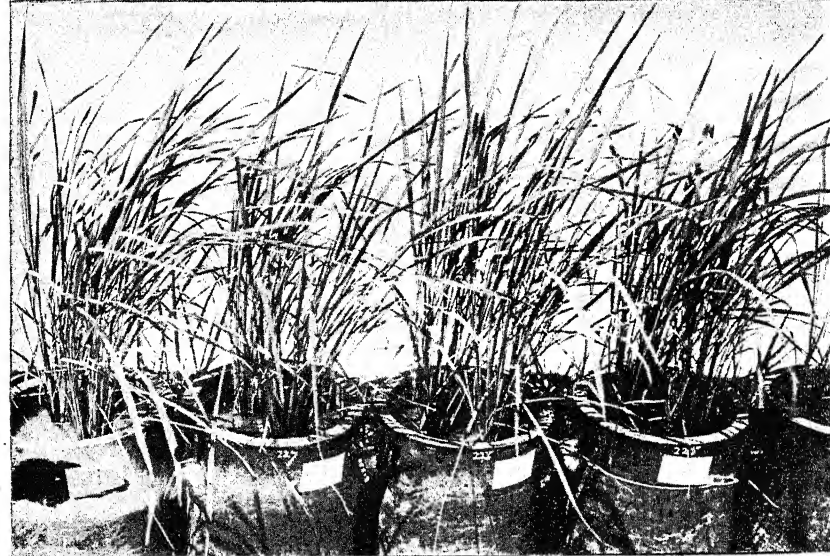
Growth of 21 weeks.

TANTABIN (A) SOIL.

NO MANURE



NITROGEN



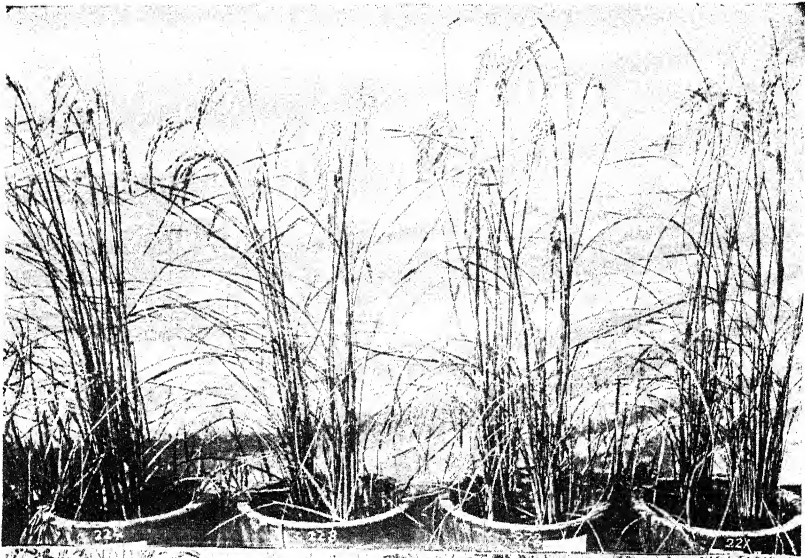
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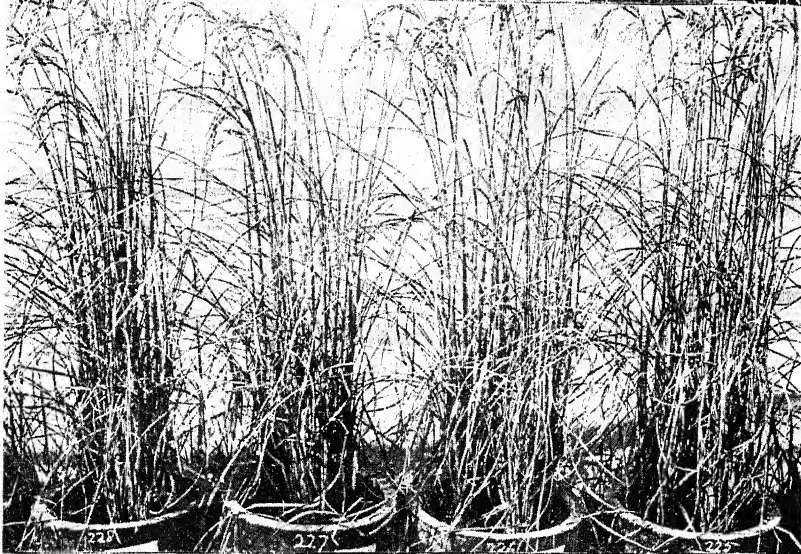
Growth of 4 weeks

TANTABIN (A) SOIL.

NO MANURE



NITROGEN



PHOSPHORUS AND NITROGEN



INSEIN (A) SOIL.

NO MANURE



NITROGEN



PHOSPHORUS AND NITROGEN



INSEIN (A) SOIL.

NO MANURE



NITROGEN



PHOSPHORUS AND NITROGEN



PYINBONGYI (B) SOIL.

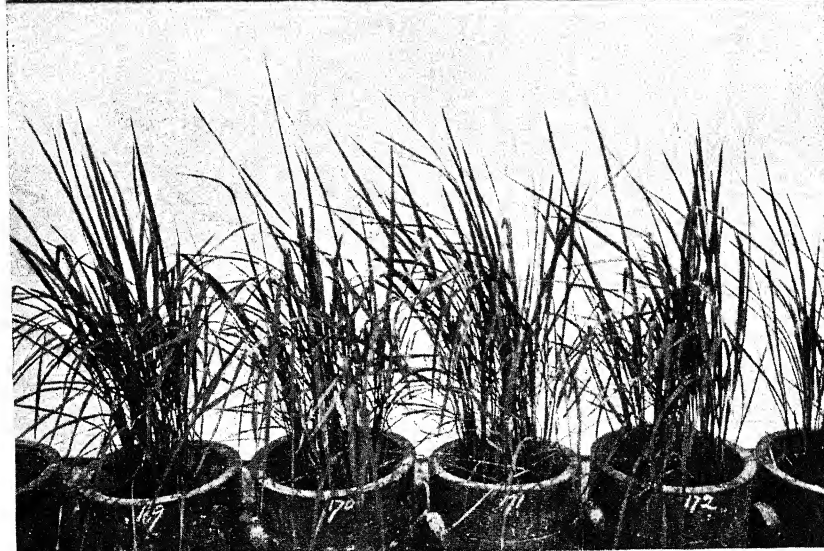
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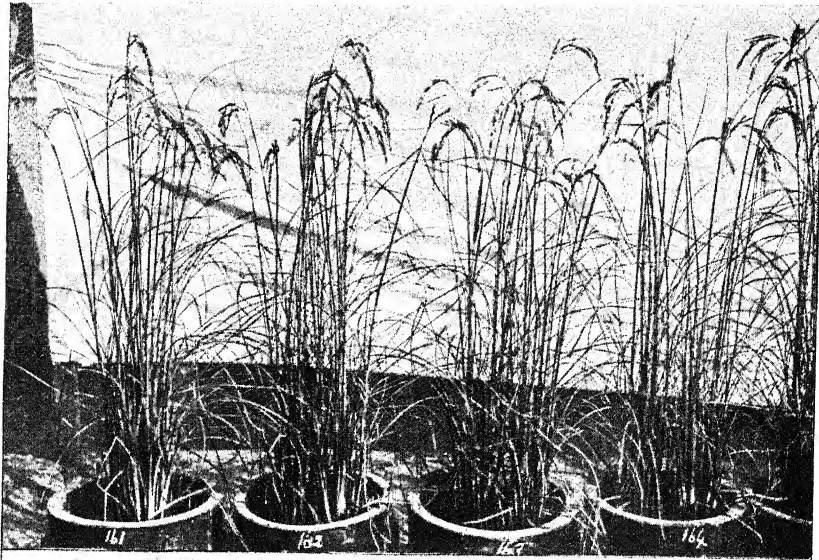
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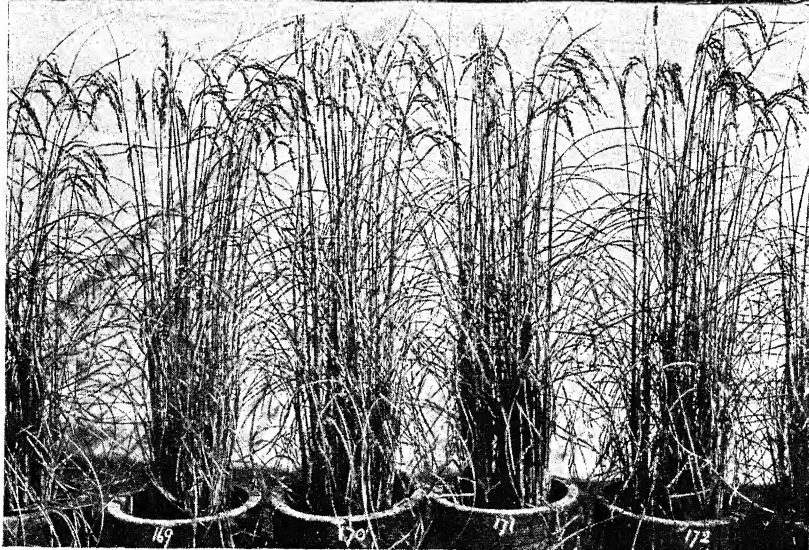
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PHOSPHORUS AND NITROGEN



ABSORPTION OF LIME BY SOILS.

BY

F. J. WARTH, B.Sc., M.Sc.,

Agricultural Chemist to the Government of Burma, Mandalay;

AND

MAUNG PO SAW,

Assistant to the Agricultural Chemist to the Government of Burma.

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PART I. INTRODUCTORY.

THE experimental work which has been done in connection with acidic properties of soils may be fairly fully considered under the two following heads :—

- (a) Effects of neutral salts on soils.
- (b) Effects of lime as hydrate carbonate or bicarbonate on soils.

The action of neutral salts on soils is generally explained as an adsorption phenomenon. Amongst the strong arguments in support of this view, the following may be mentioned. The equilibrium between the salt solution and soil has been shown to follow very accurately the adsorption isotherm.¹

The soil can absorb other substances with which it is not suspected of reacting chemically to an appreciable extent. Some dyes, oxalic and other organic acids fall under this head.²

¹ Patten and Cameron; *Journ. Phys. Chem.*, 1907, 581. Parker; *Journ. Agric. Res.*, 1913, 179. Aberson; *Kolloid Z.*, 1912, X, 13. Wiegner; *J. f. Landw.*, 1912, 111.

² Hanley; *Journ. Agric. Sci.*, 1914, 58. Patten and Cameron; *Loc. cit.* Prescott; *Journ. Agric. Sci.*, 1916.

The experiment of Pratolongo (quoted by Prescott) on the absorption of phosphoric acid by calcareous and non-calcareous soils supports in a striking manner the adsorption theory.

On the other hand, it has been known from the earliest days of these soil studies that the action of neutral salts leads to a substitution of bases in practically theoretical chemical proportions.¹

Such a substitution is generally considered to be a chemical reaction.

Hall and Gimingham² have shown that, within the ranges of concentration tested, the action of ammonium chloride on soil follows the law of mass action, and must therefore be considered a purely chemical reaction.

The acidity developed when certain soils are treated with neutral salts may be explained as an adsorption phenomenon because the equilibrium follows the usual adsorption isotherm. The acidity has, however, been traced generally to the presence of aluminium salts in solution³, and it must be admitted that their presence suggests a more fundamental change than purely physical adsorption, unless our views regarding the constitution of some aluminium silicate compounds require to be modified. This does not seem unlikely.

Lachs and Michaelis⁴ have shown that many of the typical absorption phenomena of soils, including substitution of bases by the action of neutral salts, can be reproduced by charcoal, the conclusion being that soil acts similarly to the typical adsorbing medium charcoal.

The discussion over this debated ground is simplified if we admit, as is unquestionably the case, that, in the reacting liquid, chemical changes undoubtedly occur, and that the reaction therefore is always purely chemical in one sense. The undecided point is whether the displaceable bases in the soil occur (*a*) as true compounds or less definite additive compounds, or (*b*) in a purely physically adsorbed state.

It is perhaps from further study of the so-called acid soils, in which the absorbing power of the soil for bases is unsatisfied (Daikuhara), that more definite information on this point may be expected.

In these soils neutral salts effect very little displacement (except of alumina), nor has any appreciable direct absorption of base with equivalent liberation of mineral acid been observed.

¹ Way; 1850. Peters; 1860. Parker; *Loc. cit.* Rice; *Journ. Chem. Soc.*, 1916, A—1, 360.

² Hall and Gimingham; *Journ. Chem. Soc.*, 1907, 677.

³ Conner; *Journ. Soc. Chem. Ind.*, 1916, 551. Rice; *Loc. cit.* Daikuhara; *Journ. Soc. Chem. Ind.*, 1914, 877.

⁴ *Z. f. Electroch.*, 1911, 17—1.

Such soils, however, readily absorb bases from alkaline liquids including lime as hydrate carbonate and bicarbonate, and the mode of this absorption is the crucial question.

Lime, as hydrate carbonate or bicarbonate, has been used in laboratory soil tests, principally to discover empirical laboratory processes which would give lime requirement figures comparable either with plant growth in field and pot cultures or with azotobacter developments.¹ There is scope therefore for a more full study of the absorption of lime by soils.

This has been attempted in the experiments described in the present paper by acting upon soils with calcium bicarbonate solutions containing varying amounts of carbonic acid.

The experiments were carried out in connection with an enquiry into the nature of certain types of soil acidity in Burma. It was thought that if the organic and inorganic soil constituents possessed decidedly different powers of absorbing lime, broken absorption curves would be obtained by these tests, and thus some information obtained regarding the nature of the soil acidity.

The work has shown that absorption is remarkably regular. The results therefore have not helped us in the way hoped for. They have, however, shown up some points regarding lime absorption which are worth recording.

It has been found that the soil and carbonic acid enter into competition for the base and an equilibrium is established which depends upon the concentration of the carbon dioxide in solution.

It is quite possible that the absorption of lime follows the exponential law. Owing to experimental difficulties which will be appreciated later, we have so far not attempted to test this point.

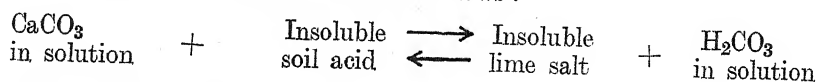
However, whether the absorption does or does not follow this law, the equilibrium between lime, carbonic acid, and soil may still be explained as a chemical reaction. We have for this purpose to assume that colloidal acidic bodies exist in acid soils. It may be noted here that some soils are capable of inverting sucrose solution in a manner analogous to the action of acids.² The colloids being of a complex hydrated nature must be, if they are acidic, polybasic acids in which the basicity is so high that we have what is equivalent to a continuous series of acidic bodies of increasing strength.

¹ Veitch; *Journ. Chem. Soc.*, 1904, A—2, 600. McIntyre and Willis; *Journ. Soc. Chem. Ind.*, 1915, 93 and 438. Hutchinson and McLennan; *Journ. Agric. Sci.*, 1915, 75. Christensen; *Ex. St. Records*, 1917, Vol. XXXVI.

² Hanley. *Journ. Agric. Sci.*, 1914, 59.

The neutral colloids of more nearly neutral soils would in the same way not be devoid of acidic properties. Such substances will possess an amphoteric character and will be able under the influence of alkalis to assume a gradation of acid characters.

The action of calcium carbonate on any one member of this continuous series of insoluble acid bodies will be as follows :—



The velocities of the direct and reverse reactions will therefore be respectively proportional to calcium carbonate and carbonic acid in solution (the concentrations of soil acid and its lime compound being constants). At the point of equilibrium, therefore, the quotient $\frac{\text{CaCO}_3 \text{ in solution}}{\text{CO}_2 \text{ in solution}} = R$ will be a constant for this acid.

For each of the acids of the assumed series there will be such a constant. It is evident that with decreasing acid strength the quotient will have an increasing value, the final term being a value for R which would be in equilibrium with solid calcium carbonate. This would be reached when the soil acids have been neutralized with reference to calcium carbonate.

If lime in solution is in excess of the quantity demanded for the quotient R , absorption will take place until the constant has been attained or the acid neutralized.

With lower calcium carbonate, solution-concentration lime must be extracted from this particular lime acid compound, either completely or until solution-concentration rises to R .

The application of this principle to a soil (assumed to contain a continuous series of acids), when treated with bicarbonate solution, leads to the following result :—

The weakest acid in which combination can take place is the one for which R is equal to the ratio $\frac{\text{CaCO}_3}{\text{CO}_2}$ in solution when equilibrium between soil and solution has been attained.

All the members stronger than this one will have formed lime compounds; the members weaker than this one cannot take up any lime from this solution.

The lime absorbed in this case is the amount required to combine with the acids specified and is therefore a definite quantity. It may be observed that the same amount of lime absorption should be attained using bicarbonate solutions of different initial strengths and also different strengths at the

attainment of equilibrium. The only condition for equal absorption in every case being that, when equilibrium has been established, the ratio $\frac{\text{CaCO}_3}{\text{CO}_2}$ in solution shall be the same.

If equilibrium is attained when R has a higher value, clearly some of the acids which were not able to absorb lime in the case just considered will be able to do so now. The total lime absorbed by the soil will therefore be more.

The total lime absorbed by a soil should accordingly be a function of the quotient R.

Owing to changes in degree of ionisation and to the fact that we are not dealing with pure calcium carbonate solutions (effect of displacement), it cannot be expected that the value of R will for any given acid remain absolutely constant for all dilutions.

Within the moderate ranges of dilution tested, the differences should be scarcely greater than the errors of experiment.

A reference to the experimental results shows that, as far as they go, the figures of Table II support the assumptions made above.

PART II. EXPERIMENTAL.

1. DESCRIPTION OF SOILS USED.

The figures of the accompanying Table I show the composition of the soils :—

TABLE I.

LABORATORY NO. OF 1916	844	846	845	848	—	867
Name of soils	Hlegu	Hmawbi	Mandalay	Pwinbyu	Hopin	Sahmaw
Insoluble residue ..	73.82	68.47	55.80	59.53	71.39	48.11
Soluble silica ..	11.53	13.11	19.20	12.65	12.37	18.08
Ferric oxide (Fe_2O_3)	1.15	3.62	4.26	5.91	2.85	10.08
Alumina (Al_2O_3) ..	8.29	9.37	14.00	13.93	7.47	14.20
Lime (CaO) ..	0.36	0.32	0.82	0.66	0.58	0.97
Magnesia (MgO) ..	0.07	0.13	0.15	0.21	0.32	0.42
Potash (K_2O) ..	0.25	0.49	0.89	0.99	0.31	0.26
Soda (Na_2O) ..	0.11	0.24	0.30	0.23	0.10	0.11
Sulphuric acid (SO_3)	0.06	0.04	0.06	0.20	0.07	0.08
Phosphoric acid (P_2O_5)	0.02	0.03	0.04	0.13	0.04	0.04
Carbon dioxide (CO_2)	0.03	0.02	0.31	0.12	0.02	0.02
Organic matter + ..	4.62	4.16	4.17	5.44	4.48	7.62
Combined water ..	..	..	..	..	..	..
TOTAL ..	100.00	100.00	100.00	100.00	100.00	100.00
Organic carbon ..	1.3940	0.8780	0.7900	0.9640	1.3130	1.5780
Organic nitrogen ..	0.1162	0.0724	0.0720	0.1100	0.1090	0.1320
Available phosphoric acid.	0.0007	0.0029	0.0106	0.0489	0.0104	0.0065
Available potash ..	0.0064	0.0147	0.0271	0.0275	0.0205	0.0290

The samples are typical of large characteristic soil formations of Lower, Middle and Northern Burma respectively.

(a) Hlegu and Hmawbi soils are typical of the leached out soils of Lower Burma. They contain very small amounts of alkaline earths and not much potash. The deficiency of potash is, however, not generally serious compared with the deficiency of lime.

Hlegu is rich in organic matter but this must occur in a remarkably disintegrated state if soil colour is any index. This soil is dark but not black, whilst Hopin giving a lower organic carbon figure is quite black when moist. Both these soils are decidedly acid.

(b) Mandalay and Pwinbyu are new soils formed on recent alluvial deposits. They are rich in alkalis and alkali earths. Both are alkaline.

(c) Hopin and Sahmaw are typical marsh soils of Northern Burma. They are well supplied with alkaline earths and are rich in organic matter. They contain, however, no more potash than the Lower Burma soils. This fact emphasizes the marshy conditions under which they occur. These soils are also acid.

The test for acidity with litmus paper is worth remarking upon here. If the test paper is placed on the moist soil, Sahmaw and Hopin indicate faint alkalinity. If the paper is placed between two layers of wet soil, Sahmaw shows strong acidity and Hopin weak but definite acidity. If the papers are made to dip into a shallow layer of water on the soil, the free evaporating end of the paper becomes alkaline whilst the part in contact with soil becomes acid.

These peculiarities are clearly due to differences in diffusion of the acidic and alkaline bodies.

Hlegu and Hmawbi show acidity, and the other two soils alkalinity under all the above conditions.

2. METHOD USED IN DETERMINING LIME ABSORPTION.

Without going further into the matter at present, it is to be expected that the amount of lime absorbed by a soil from calcium bicarbonate solution will depend upon concentrations of lime and of carbonic acid in solution.

The experimental work, therefore, consisted in determining the amount of lime absorbed from bicarbonate solution containing different amounts of lime and carbonic acid.

A weighed quantity of soil was placed in a bottle. A definite volume of calcium bicarbonate solution of known strength was added. The bottle closed

with greased stopper or bung was placed in a constant temperature bath (at 25°C.), and the contents shaken periodically.

A number of trials showed that equilibrium was not attained in 3 hours. Treatment for 6, 12, and 24 hours gave practically identical results. Six hours' treatment was, therefore, employed throughout these experiments.

To determine the amount of absorption which has taken place, the liquid is filtered and a fraction titrated. We obtain hence the amount of lime left in solution and by difference the amount absorbed.

Filtration is not a desirable process when we are dealing with liquids whose activity depends upon the amount of carbonic acid in solution. This could not be avoided. It is possible, however, to minimize errors by having a tall column of liquid by filtering quickly and by rejecting the first and last fractions of the filtrate. The accuracy of the results of course varied with the amount of absorption.

The corresponding carbonic acid determinations were carried out as follows:—

The bottle containing soil and bicarbonate was treated exactly as above to attain equilibrium. Soil was then allowed to settle. The liquid was syphoned off and a fraction (usually 50 c.c.) run into a 100 c.c. flask containing a measured amount of standard baryta. The flask was filled up to the mark with carbonic-acid-free water, shaken, and allowed to settle 24 hours.

The clear liquid was then syphoned off and a fraction titrated. The loss in strength represented the baryta precipitated as carbonate.

This method was found to give satisfactory results, provided that the strength of baryta was adjusted according to the amount of CO_2 to be determined

A specially adapted syphon to run off the clear liquid at a suitable rate was found to be essential.

By these means the lime remaining in solution and the corresponding concentration of CO_2 in solution was determined.

3. ABSORPTION OF LIME BY HLEGU AND HMAWBI SOILS.

The absorption was determined with bicarbonate solution of four strengths, each strength of bicarbonate being tested in presence of four different concentrations of carbonic acid. Low concentrations of carbonic acid were avoided to prevent precipitation of lime. For each test 5 gm. of soil were used.

Table II contains the experimental data obtained :—

TABLE II.

Action of calcium bicarbonate solutions on Hlegu and Hmaubi soils.

HLEGU					HMAUBI				
Strength of bicarbonate solution	CaCO ₃ absorbed	CaCO ₃ in solution	CO ₂ in solution	R	Strength of bicarbonate solution	CaCO ₃ absorbed	CaCO ₃ in solution	CO ₂ in solution	R
1st series. 100 c.c. = 0.0144 grm. CaCO ₃	0.0104	0.0040	0.0095	0.421	1st series. 100 c.c. = 0.0138 grm. CaCO ₃	0.0048	0.0090	0.0086	1.045
	0.0082	0.0062	0.0253	0.245		0.0032	0.0106	0.0182	0.583
	0.0071	0.0073	0.0411	0.177		0.0020	0.0118	0.0288	0.410
	0.0067	0.0077	0.0413	0.182		0.0008	0.0130	0.0356	0.365
	0.0058	0.0086	0.0559	0.154		0.0000	0.0138	0.0497	0.278
2nd series. 100 c.c. = 0.0288 grm. CaCO ₃	0.0146	0.0142	0.0163	0.871	2nd series. 100 c.c. = 0.0250 grm. CaCO ₃	0.0064	0.0186	0.0169	1.103
	0.0126	0.0162	0.0317	0.511		0.0044	0.0206	0.0310	0.665
	0.0116	0.0172	0.0462	0.372		0.0030	0.0220	0.0405	0.543
	0.0086	0.0202	0.0572	0.353		0.0026	0.0224	0.0480	0.467
	0.0060	0.0228	0.0770	0.296		0.0014	0.0234	0.0585	0.400
3rd series. 100 c.c. = 0.0436 grm. CaCO ₃	0.0162	0.0274	0.0295	0.929	3rd series. 100 c.c. = 0.0412 grm. CaCO ₃	0.0092	0.0320	0.0277	1.155
	0.0136	0.0300	0.0431	0.696		0.0076	0.0336	0.0392	0.857
	0.0112	0.0324	0.0581	0.558		0.0058	0.0354	0.0488	0.725
	0.0096	0.0340	0.0735	0.462		0.0038	0.0374	0.0629	0.595
	0.0102	0.0334	0.0959	0.348		0.0020	0.0392	0.0708	0.554
4th series. 100 c.c. = 0.0582 grm. CaCO ₃	0.0184	0.0398	0.0400	0.995	4th series. 100 c.c. = 0.0570 grm. CaCO ₃	0.0100	0.0470	0.0378	1.243
	0.0160	0.0422	0.0532	0.793		0.0076	0.0494	0.0475	1.040
	0.0150	0.0432	0.0581	0.743		0.0056	0.0514	0.0576	0.893
	0.0142	0.0440	0.0678	0.649		0.0052	0.0518	0.0612	0.846
	0.0142	0.0440	0.0682	0.645		0.0042	0.0528	0.0726	0.727
Addi- tional series.	0.0046	0.0048	0.0431	0.111					
	0.0034	0.0061	0.0629	0.097					
	0.0012	0.0018	0.0405	0.044					
	0.0016	0.0040	0.0828	0.048					

It must be noted that the action of calcium bicarbonate is more complex than here assumed. In addition to absorption an appreciable amount of displacement of magnesia and alkalis must take place.

For the present, however, the total alkalinity of the solution in equilibrium with soil is calculated as calcium carbonate.

The results are also shown plotted in curves (Charts I—IV).

It may be noted from these that lime absorption is a regular process, the experimental figures, which are indicated by prominent dots, conforming on the whole closely to definite curves.

How the latter were obtained will be shown later.

For each soil there are four distinct curves corresponding to the four different original strengths of bicarbonate used. The relationship between these four distinct curves will be established later.

In all cases increasing concentration of CO_2 reduces the amount of lime absorbed. With less acid soils it will be seen later that absorption is inhibited by moderate concentrations of CO_2 , and with further increase of CO_2 extraction commences. A consideration of this point will give us a clue to the nature of the equilibrium which is established between CaCO_3 , CO_2 , and acid soils.

4. RELATION BETWEEN LIME ABSORPTION AND THE QUOTIENT R.

From Table II we can take out values for lime absorbed and the corresponding values for R, all determined experimentally.

These figures entered on square paper are shown in Chart V.

Experimental errors are no doubt considerable in a few instances. The effect of dilution is also just noticeable. These defects, however, do not obscure the fact that the figures obtained from four different solution strengths have in this case coalesced to form a single curve.

In other words, lime absorbed is, within these ranges of concentration, a function of the quotient R as was demanded by theory.

The actual relationship existing between R and L, as determined experimentally for these two soils, is given by the smoothed graphs in this chart.

It is from these graphs that the curves of Charts I—IV were calculated as follows:—Taking Charts I and II, Series 4,

with original strength of bicarbonate

= 0.057 gm. per 100 c.c.

Let amount of absorption L be = 0.008 " "

Then CaCO_3 remaining in solution = 0.049 " "

From Chart V we find that when L (lime absorbed) = 0.008, the

quotient $R = 1.05 = \frac{\text{CaCO}_3 \text{ in solution}}{\text{CO}_2 \text{ in solution}} = \frac{0.049 \text{ CaCO}_3 \text{ in solution.}}{\text{CO}_2 \text{ in solution.}}$

Therefore CO_2 in solution = 0.0466 gm. per 100 c.c., i.e., having original concentration 0.057 gm. CaCO_3 , we find that 0.008 gm. CaCO_3 will be absorbed when CO_2 concentration is 0.047 gm. per 100 c.c. In this way one point on the curve of Series IV, Charts I and II, has been calculated. Using other values of L a series of points can be calculated and the curve drawn in.

The curve for the third series in the same charts can be calculated in an identical manner, in this case using the figure 0.0412 for original strength of bicarbonate.

CHART I.

Hmawbi Soil.

Strength of bicarbonate solution in equilibrium with soil.

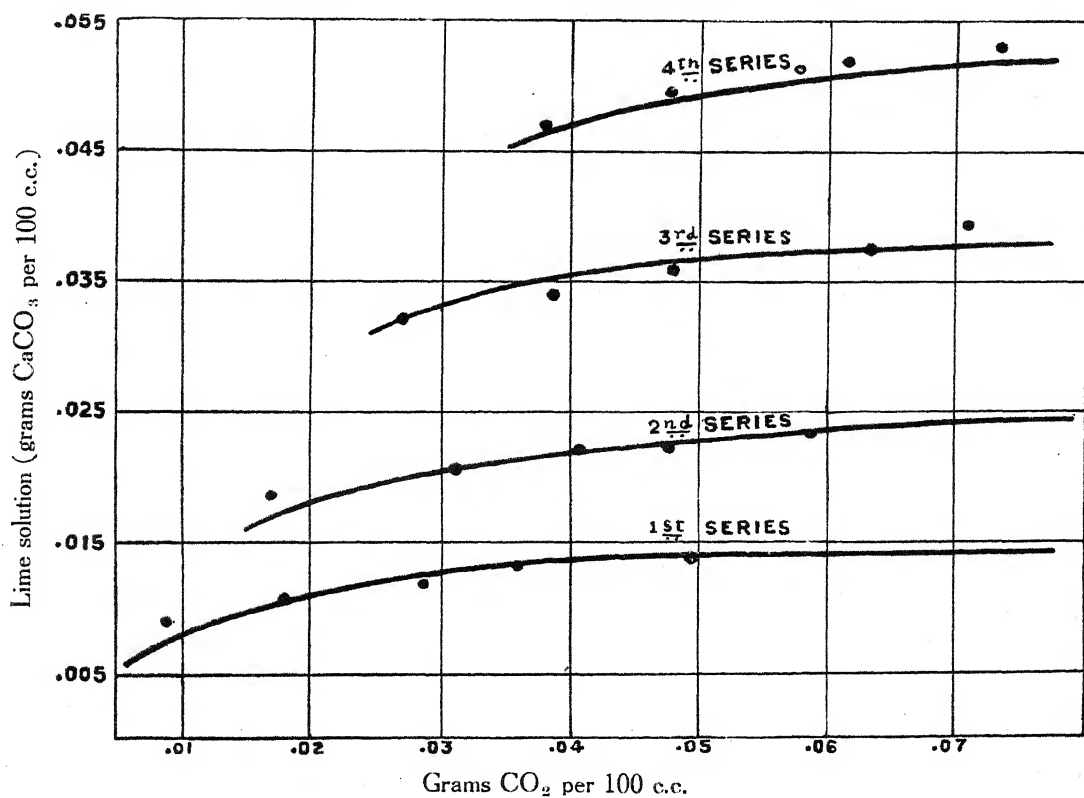
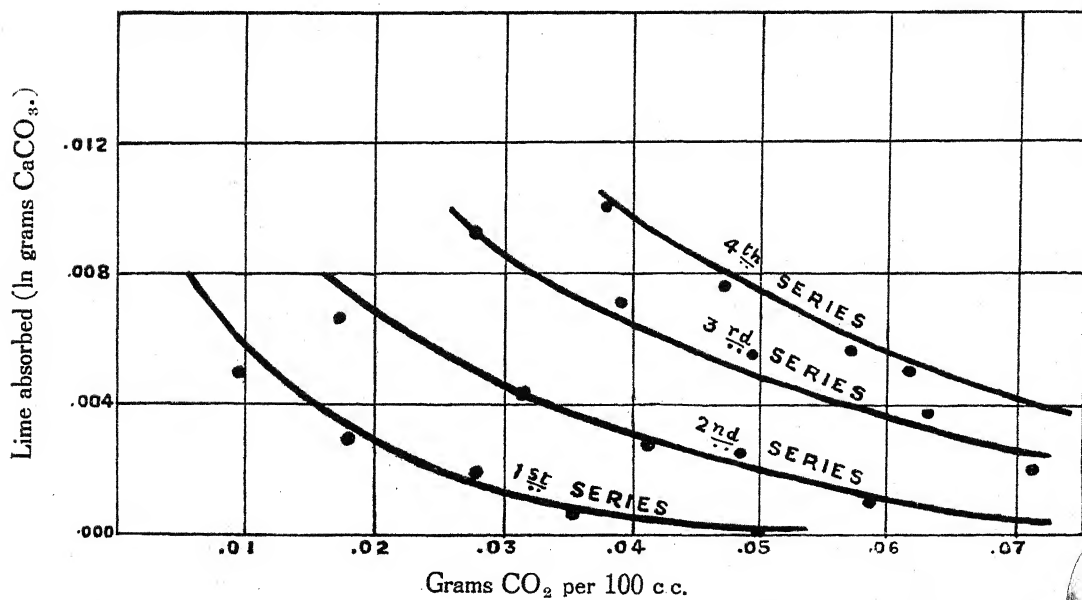
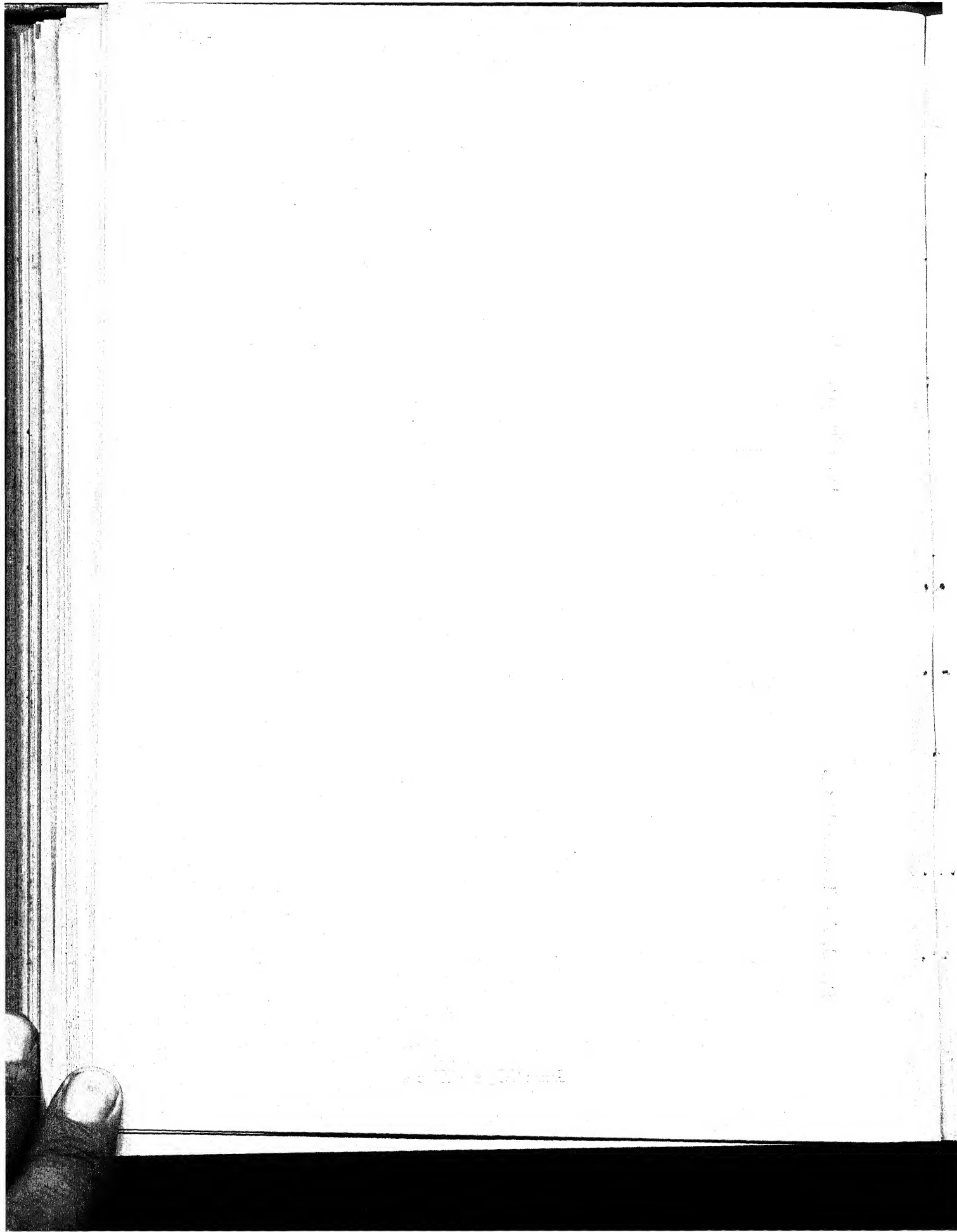


CHART II.

Hmawbi Soil.

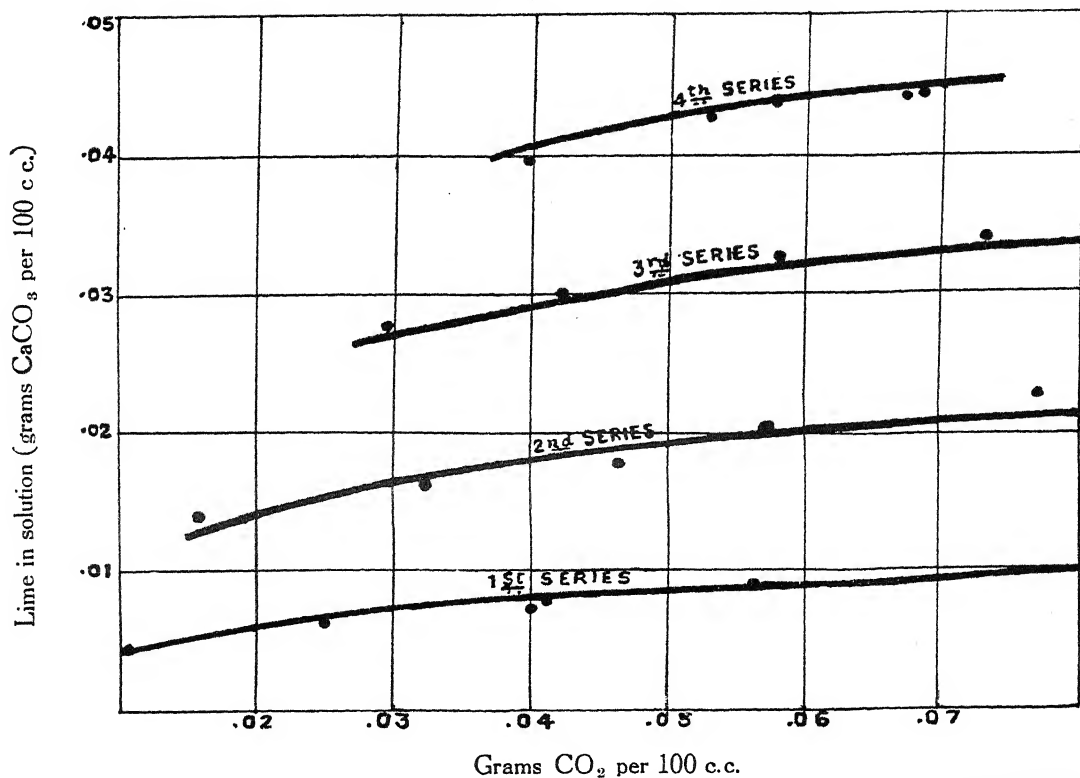
Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.





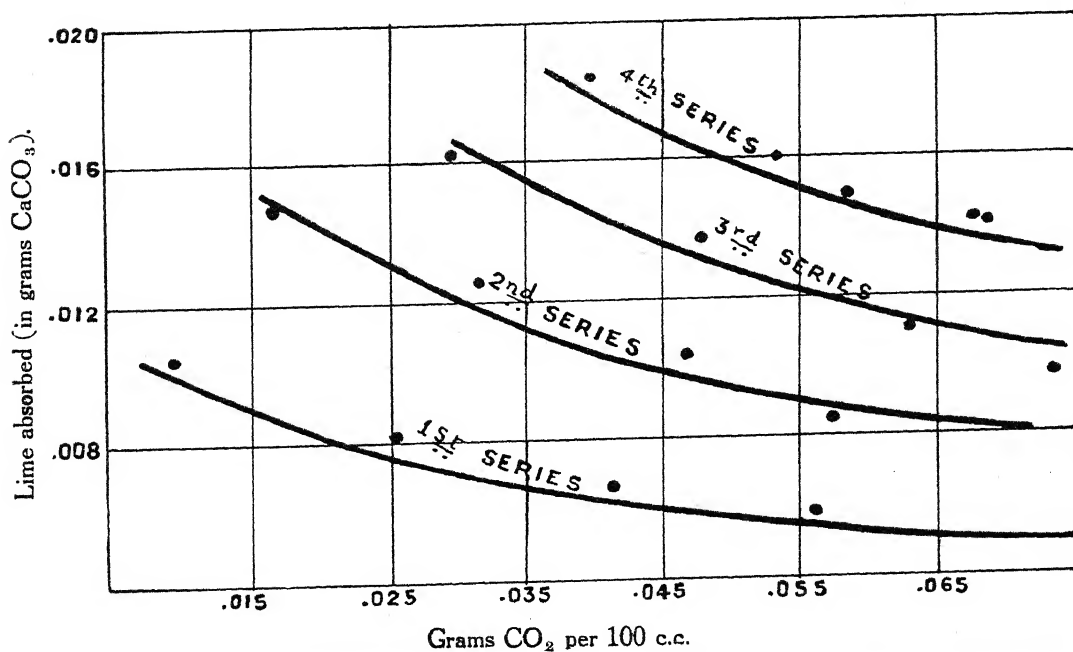
Hlegu Soil.

Strength of bicarbonate solution in equilibrium with soil.

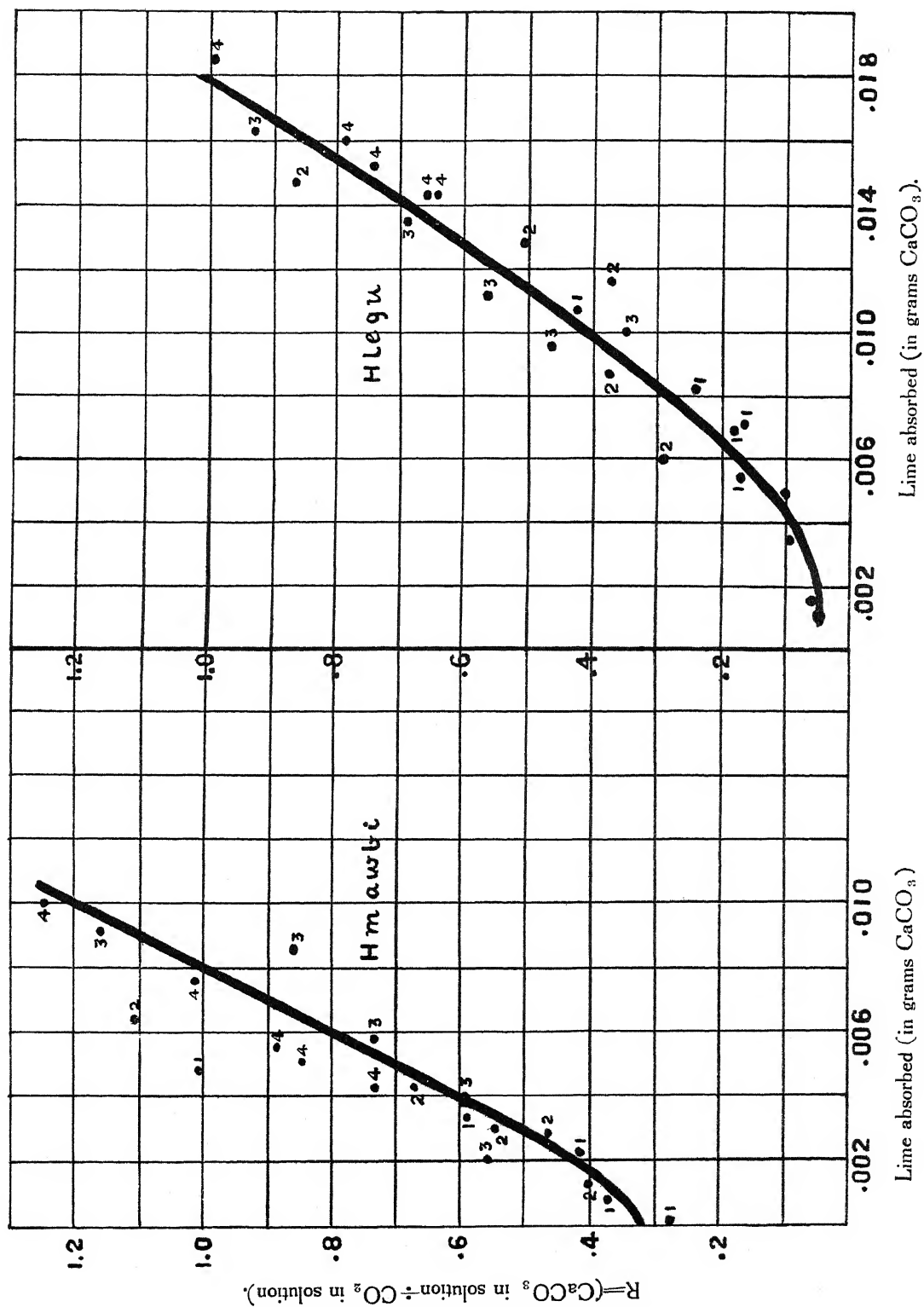


Hlegu Soil.

Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.



Relation between quantity of lime absorbed and the quotient R.



The four distinct curves of Chart I are seen in this way to be related to one another through the single Hmawbi curve of Chart V. Similarly the four distinct curves of Chart III are related to one another through the single Hlegu curve of Chart V.

It may be claimed that the discussion of these results has thrown some light on the avidity of soils for lime.

5. ACTION OF CALCIUM BICARBONATE SOLUTIONS ON SAHMAW, HOPIN, PWINBYU AND MANDALAY SOILS.

The determinations were carried out as already explained. In this case only two strengths of bicarbonate were tested.

The figures obtained are shown in Table III.

TABLE III.

Action of calcium bicarbonate solution on Hopin, Sahmaw, Mandalay and Pwinbyu soils.

HOPIN					SAHMAW				
Strength of bicarbonate solution	CaCO ₃ absorbed	CaCO ₃ in solution	CO ₂ in solution	R	Strength of bicarbonate solution	CaCO ₃ absorbed	CaCO ₃ in solution	CO ₂ in solution	R
Series 100 c.c. = 0.0246 gm. CaCO ₃	0.0032	0.0214	0.1760	1.216	Series 100 c.c. = 0.0280 gm. CaCO ₃	0.0071	0.0209	0.0193	1.083
	0.0004	0.0242	0.0268	0.903		0.0039	0.0241	0.0344	0.701
	0.0012	0.0258	0.0352	0.733		0.0027	0.0253	0.0504	0.502
	0.0032	0.0278	0.0506	0.550		0.0016	0.0264	0.0649	0.407
	..	..	..	..		0.0004	0.0276	0.0966	0.286
Series 100 c.c. = 0.0490 gm. CaCO ₃	0.0074	0.0420	0.0312	1.346	Series 100 c.c. = 0.0564 gm. CaCO ₃	0.0088	0.0476	0.0419	1.185
	0.0036	0.0458	0.0427	1.072		0.0066	0.0498	0.0554	0.899
	0.0020	0.0474	0.0497	0.954		0.0049	0.0515	0.0632	0.815
	0.0004	0.0498	0.0642	0.775		0.0037	0.0527	0.0725	0.727
	..	..	..	..		0.0027	0.0537	0.0932	0.576
MANDALAY					PWINBYU				
Strength of bicarbonate solution	CaCO ₃ excess	CaCO ₃ in solution	CO ₂ in solution	R	Strength of bicarbonate solution	CaCO ₃ excess	CaCO ₃ in solution	CO ₂ in solution	R
Series 100 c.c. = 0.0246 gm. CaCO ₃	0.0010	0.0256	0.0180	1.422	Series 100 c.c. = 0.0262 gm. CaCO ₃	0.0008	0.0254	0.0169	1.505
	0.0072	0.0318	0.0290	1.096		0.0016	0.0278	0.0262	1.061
	0.0100	0.0346	0.0352	0.983		0.0042	0.0304	0.0356	0.854
	0.0126	0.0372	0.0497	0.730		0.0065	0.0327	0.0493	0.663
	..	..	..	..		0.0078	0.0340	0.0559	0.608
Series 100 c.c. = 0.0490 gm. CaCO ₃	0.0014	0.0480	0.0326	1.472	Series 100 c.c. = 0.0482 gm. CaCO ₃	0.0044	0.0460	0.0312	1.474
	0.0016	0.0510	0.0427	1.200		0.0006	0.0488	0.0427	1.143
	0.0042	0.0536	0.0506	1.060		0.0018	0.0500	0.0488	1.025
	0.0080	0.0574	0.0651	0.880		0.0034	0.0516	0.0585	0.882
	..	..	..	..		0.0044	0.0526	0.0629	0.836

Corresponding values of L and R were determined and absorption curves derived from these exactly as explained in case of Hlegu and Hmawbi.

Charts VI and VII show the curves obtained for Sahmaw and Hopin soils. The results of actual determinations are indicated by points showing that the calculated curves do not depart seriously from the bulk of the experimental figures.

Hopin results are notable in that we find here for the first time negative absorption or extraction taking place.

That there is no appreciable break in the curve in this case is a further proof of the general applicability of the conclusions already arrived at regarding absorption of lime by soils.

6. COMPARISON OF THE LIME-ABSORBING POWERS OF THE SIX SOILS EXAMINED.

Once we have determined by experiment the curve $L = f(R)$ for any soil, we can calculate the absorption which would take place with solutions of any strength.

The absorption that would take place from solutions of bicarbonate containing 0.05 gram. CaCO_3 per 100 c.c., has been calculated accordingly and the figures are shown graphically in Charts VIII and IX.

These charts enable us to compare more completely the lime absorption power of the soils.

In Chart VIII, the parts of the curve below the zero line indicate the amount of lime extracted from the soil.

Chart IX shows strength of solution remaining in equilibrium with the soil after absorption or extraction has taken place.

The dotted line marks the concentration of the original solution. The distances between the dotted line and curve give the amount of absorption or extraction which has taken place to attain equilibrium.

One important point remains to be discussed. Can these figures be made to yield information regarding the actual lime requirement of these soils?

If we assume that Pwinbyu is agriculturally a neutral soil, we have to conclude from Chart IX that a neutral soil will absorb no lime from a bicarbonate solution containing 0.05 gram. CaCO_3 and 0.045 gram. CO_2 per 100 c.c. liquid. At this equilibrium point we know further that $R = 1.11$. Turning now to Hlegu soil, Chart V shows that when $R = 1.11$ this soil absorbs 0.019 CaCO_3 , i.e., 0.019 gram. of CaCO_3 must be absorbed by Hlegu soil before it can remain in equilibrium with a solution containing 0.05 gram. CaCO_3 and 0.045 gram. CO_2 per 100 c.c. Accordingly the lime requirement of 5 gram. Hlegu soil is equal to 0.019 gram. CaCO_3 .

CHART VI.

Hopin and Sahmaw soils.

Strength of bicarbonate solution in equilibrium with soils.

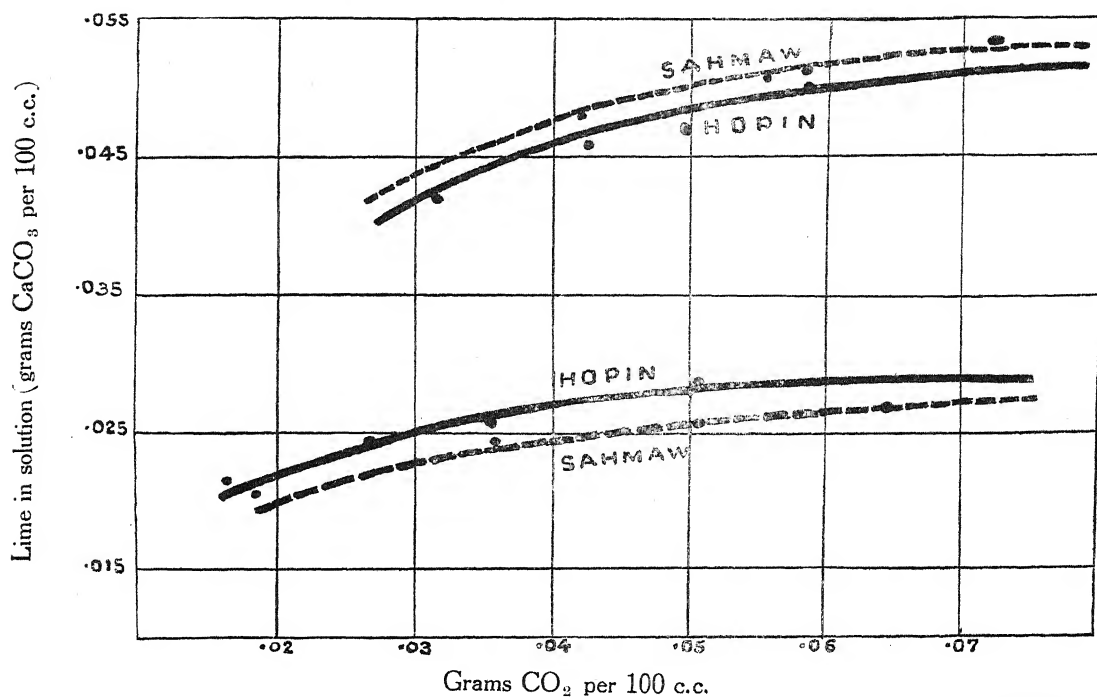


CHART VII.

Hopin and Sahmaw soils.

Lime absorbed by 5 grams of soil from different strengths of calcium bicarbonate solution.

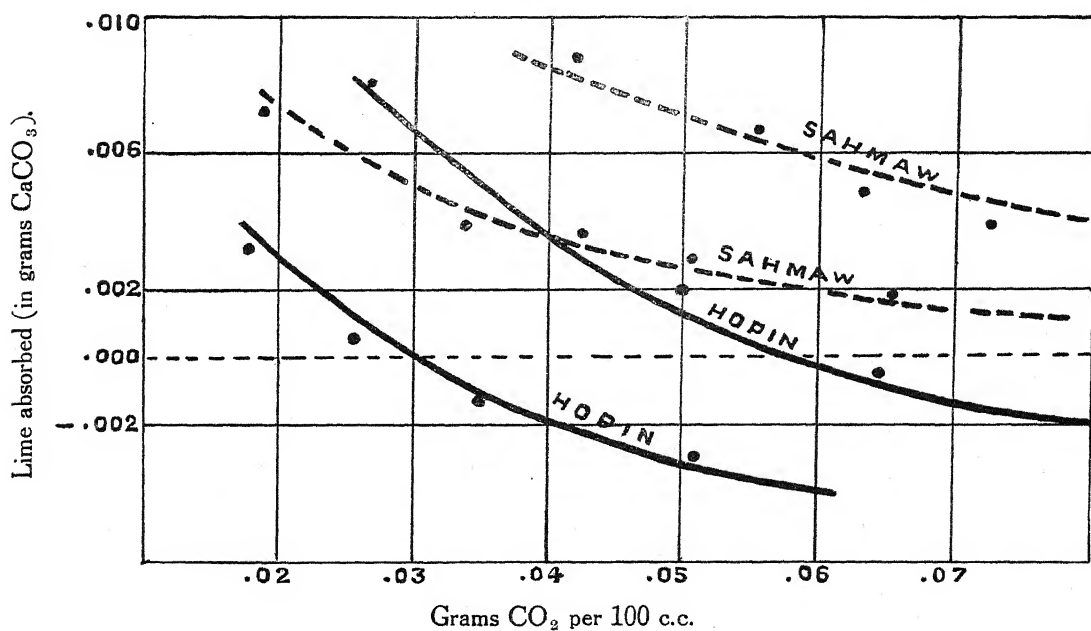
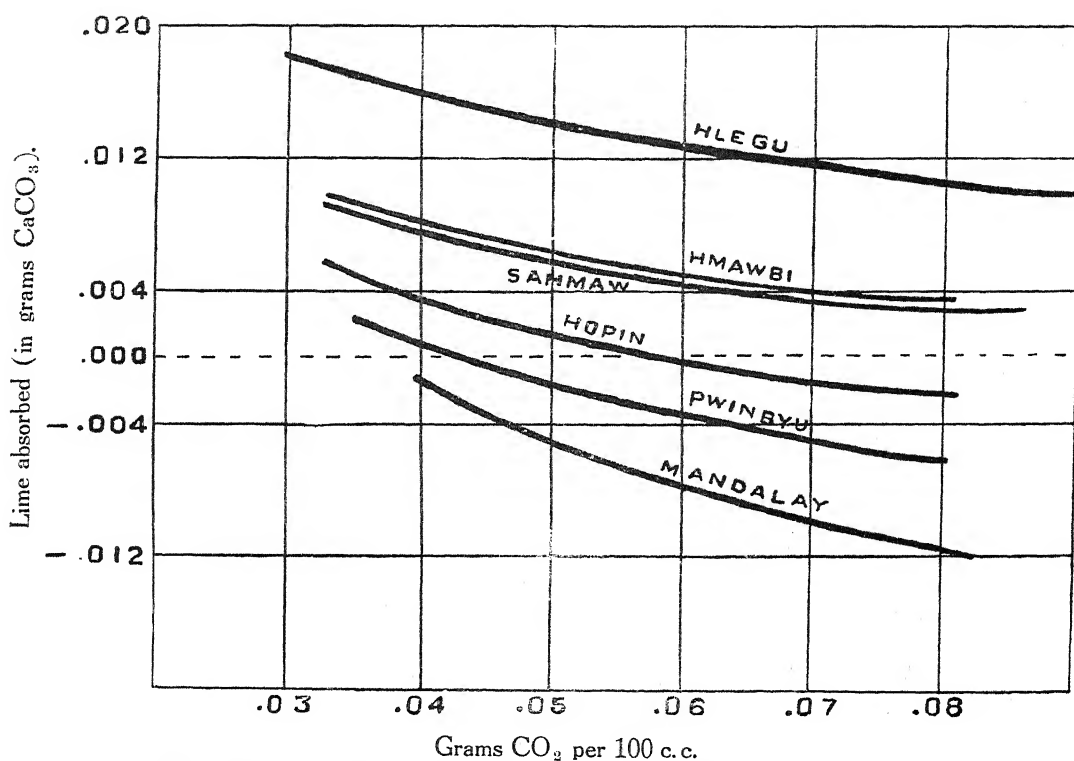


CHART VIII.

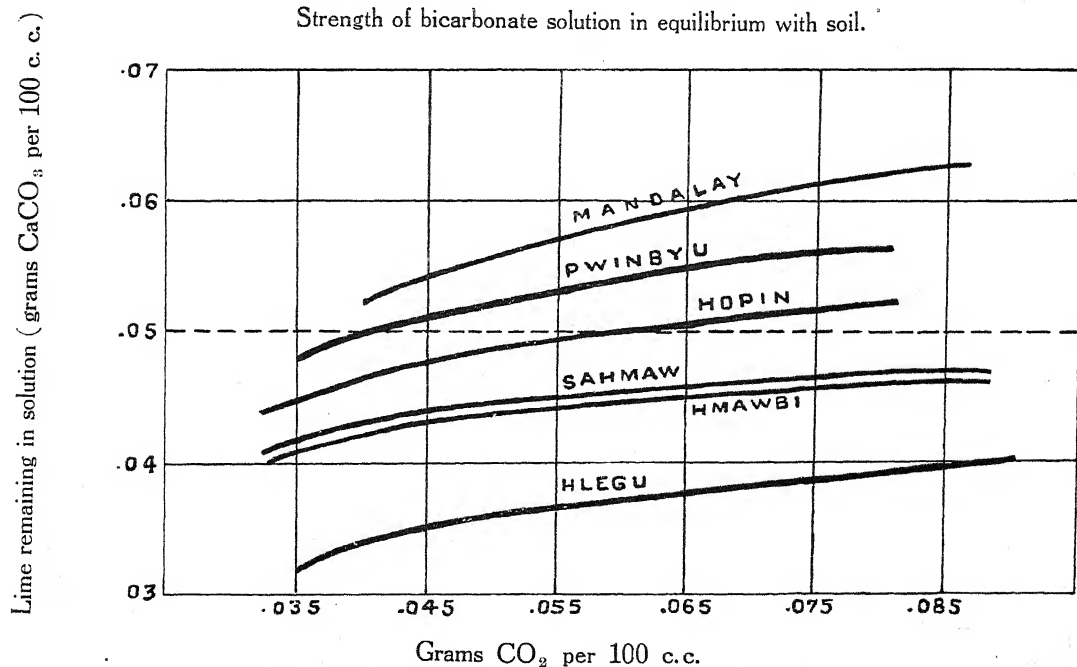
Action of different soils on bicarbonate solution of the same strength
(0.05 gm. CaCO_3 per 100 c.c.)
Lime absorbed by 5 grams of soil.



The dotted line indicates equilibrium between soil and bicarbonate solution.

CHART IX.

Strength of bicarbonate solution in equilibrium with soil.



The dotted line shows original strength of bicarbonate.

Hmawbi in the same way is found to have a lime requirement of 0.009 gm. or 0.18 per cent.

It is perhaps necessary to point out that in these calculations Pwinbyu soil has been assumed to be a typical neutral soil. As a matter of fact Pwinbyu is on the whole to be regarded as a slightly alkaline soil, and, therefore, the equilibrium solution to correspond to a truly neutral soil should contain somewhat more CO_2 than here stated. With this reservation there is no doubt that we have in this method a means of determining soil acidity which deserves some consideration.

7. TOTAL ACIDITY OF SOILS.

Before concluding, the theoretical interest of Charts I—IV deserves some consideration. To enable us to follow them back to their origin further data are required. We must know in the first place the amount of lime which the soil can absorb when in equilibrium with solid CaCO_3 in presence of CO_2 -free water.

This quantity may be defined as the total soil acidity. We must also know the solubility of CaCO_3 in carbonic acid.

The determination of the total soil acidity was made by a process similar to the Veitch method. Several lots of the soil were treated with different quantities of bicarbonate solution and evaporated to dryness. The dry soil was taken up with boiling CO_2 -free water, and, after settling, the clear liquid was examined for lime.

The lime content was determined (a) by titration, (b) by boiling vigorously for two minutes with phenol-phthalein and observing the colour developed. Results are shown in the accompanying Table IV.

TABLE IV.
Total soil acidity.

HLEGU				HMAWBI			
Bicarbonate used	REACTION OF EXTRACT		Acidity in gm. CaCO_3 absorbed	Bicarbonate used	REACTION OF EXTRACT		Acidity in gm. CaCO_3 absorbed
	Phenol-phthalein	Methyl-orange titration N HCl $\frac{1}{50}$			Phenol-phthalein	Methyl-orange titration N HCl $\frac{1}{50}$	
180	Pink	2.5	∴ Maximum absorption = 0.075 gm. CaCO_3	140	Pink	2.4	∴ Maximum absorption = 0.055 gm. CaCO_3
160	Pink	2.5		120	Pink	2.5	
140	Faint	1.7		100	Pink	2.0	
120	Very Faint	1.4		80	Very faint	1.8	
100	No	0.9	Stronger acids = 0.050 gm. CaCO_3	60	Trace	1.2	Stronger acids = 0.025 gm. CaCO_3
80	No	0.7		40	No	0.7	

TABLE IV—*contd.*

HOPIN				SAHMAW			
Bicarbonate used	REACTION OF EXTRACT		Acidity in gm. CaCO_3 absorbed	Bicarbonate used	REACTION OF EXTRACT		Acidity in gm. CaCO_3 absorbed
	Phenol- phthalein	Methyl- orange titration N HCl			Phenol- phthalein	Methyl- orange titration N HCl	
120	Pink	2.5	\therefore Maximum absorption = 0.015 gm. CaCO_3 Stronger acids = 0.015 gm. CaCO_3	140	Pink	2.5	\therefore Maximum absorption = 0.055 gm. CaCO_3 Stronger acids = 0.020 gm. CaCO_3
100	Pink	2.5		120	Pink	2.4	
80	Pink	2.1		100	Pink	2.2	
60	Faint	1.5		80	Pink	2.0	
40	Trace	1.1		60	Faint	1.5	
20	No	0.6		40	Trace	0.8	

The soils should of course absorb more lime from $\text{Ca}(\text{OH})_2$ solution but for the curves of Charts VIII and IX the CaCO_3 figures just determined are the ones we require. The maximum absorption shown in the Charts is calculated as follows for Hlegu soil :—

Soil + 100 c.c. water = 160 c.c. standard bicarbonate.
= 0.080 gm. CaCO_3 .

Lime in 100 c.c. water = 0.005 gm. CaCO_3 .

Therefore soil has absorbed 0.075 gm. CaCO_3 .

These figures are naturally far in excess of the lime requirements of these soils. Their interest at present is solely to give end points to the curves of Charts I—IV.

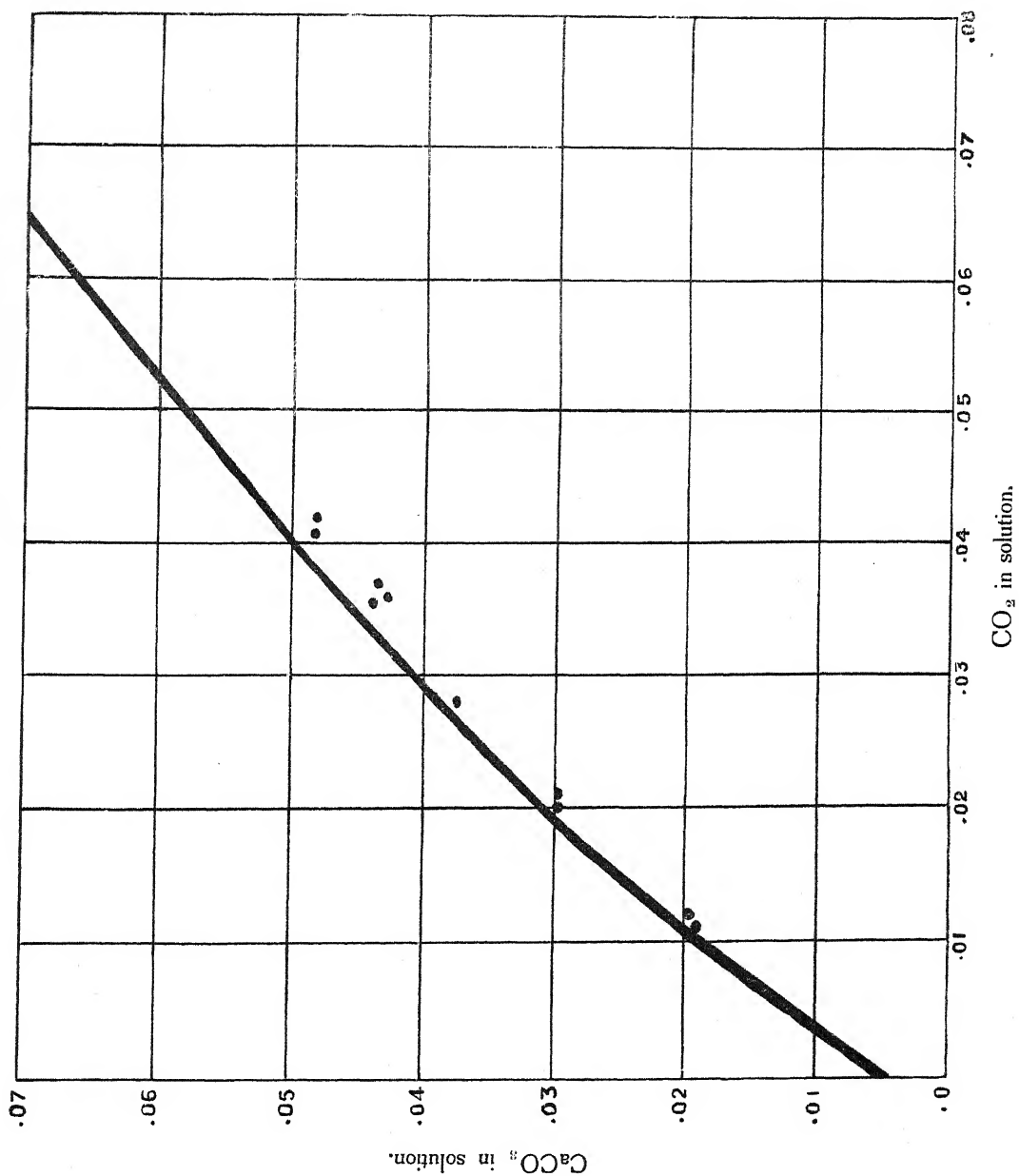
8. SOLUBILITY OF CaCO_3 IN CARBONIC ACID.

J. W. Leather (*Memoirs of the Department of Agriculture, India, Chemical Series*, Volume I, No. 7) made a full series of determinations of the solubility of CaCO_3 in water containing increasing amounts of CO_2 .

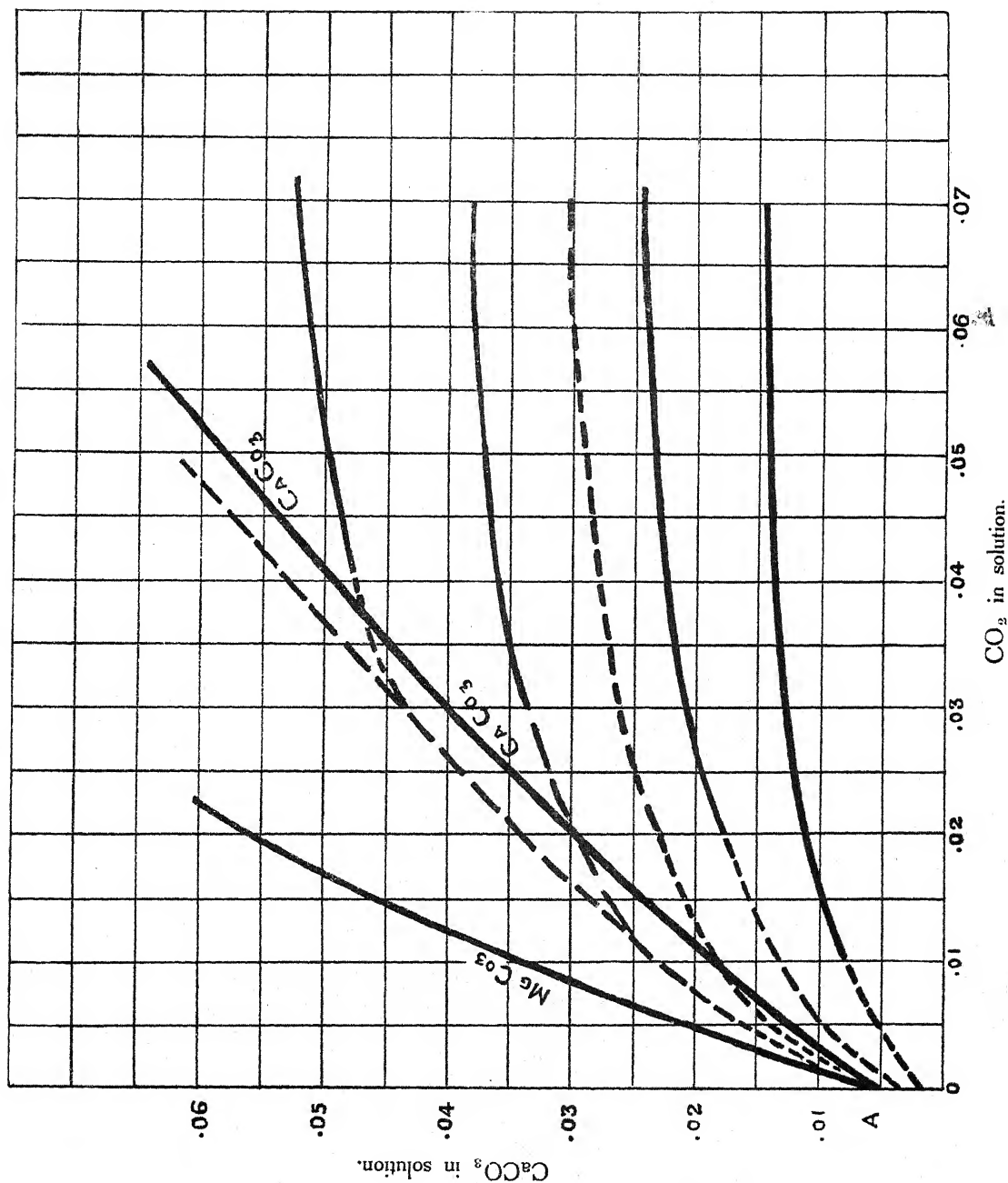
The method used in the present enquiry for lime absorption can be very easily used for determination of solubility of CaCO_3 in CO_2 water. A series of determinations was made. In Chart X our figures are plotted against Dr. Leather's graph, showing that the two series of determinations agree very well. Dr. Leather has also determined the solubility of magnesium carbonate in water containing carbonic acid. This cannot be carried out by our method without the aid of corrections in the CO_2 determinations, and has therefore not been attempted.

CHART X.

Solubility of calcium carbonate in carbonic acid.



Lime absorption curve. Hmawbi soil (Chart 1.)



9. COMPLETE LIME ABSORPTION CURVES.

Reference to Chart XI will make the matter clear. We have here in the first place the solubility curves of CaCO_3 and MgCO_3 in solutions of carbonic acid.

Next we have four incomplete curves for bicarbonate solutions in equilibrium with Hmawbi soil (Charts I—IV).

Between the second and third of these, another curve has been inserted. This has been calculated in the usual way with the aid of the graph in Chart V, using for original strength of bicarbonate 0.0325 gm. CaCO_3 per 100 c.c. (i.e., Total soil acidity + CaCO_3 soluble in 100 c.c. CO_2 -free water).

We know from the total soil acidity determinations that this curve must pass through A. The end of this curve can therefore be drawn in without having to interpolate values in Chart V. Having completed this, we are in a position to calculate approximately the shape of the undetermined extremities of the other four curves. The approximate continuations are dotted in. The points of intersection of these curves with the CaCO_3 solubility curve are of interest.

If the solution in contact with the soil consisted of pure CaCO_3 , deposition of lime (in contradistinction to absorption) would commence at this point. As the liquid contains some MgCO_3 the point of deposition will be somewhere between the CaCO_3 and MgCO_3 curves. When the amount of lime used is only slightly in excess of soil acidity the deposition point will coincide absolutely with the magnesia curve (see Leather and Sen, *Memoirs of the Department of Agriculture, Chemical Series*, Volume III, No. 8). When lime is used in great excess it must approach the CaCO_3 curve. The curve showing deposition point is indicated roughly.

PART III. CONCLUSIONS.

The experiments have given us in the first place definite information regarding conditions under which lime is removed from or absorbed by soils of different types.

It is interesting to note that the absorption must take place in a similar manner whether it is the organic or the inorganic soil constituents which effect the absorption.

This result is of interest in connection with Hanley's experiments on acidity of peat soils (*loc. cit.*). The work has further indicated an interesting method for estimating the lime requirements of a soil.

It should be mentioned finally that the more usual form of absorption curve as worked out for potash could be roughly calculated for lime also from the data supplied here.

The direct experimental determination cannot be carried out without difficulty as it would involve maintenance of constant concentration of carbonic acid in solution throughout a whole series of experiments.

As the carbonic acid plays such an important part in the equilibrium attained with lime, the curves of Charts VIII and IX are perhaps more useful than the normal absorption curve would be.

THE GASES OF SWAMP RICE SOILS.

PART V.

A METHANE-OXIDIZING BACTERIUM FROM RICE SOILS.

BY

P. A. SUBRAMANIA AIYER, B.A.,

Assistant to the Government Agricultural Chemist, Madras.

[Received for publication on 8th October, 1918.]

THE investigation of the gases of swamp rice soils has shown that the organized film overlying the surface of the soil is capable of oxidizing methane to carbon dioxide and water¹ and that this reaction is brought about by the agency of bacteria. An energetic oxidation of the gas was developed in mixed cultures of bacteria, but all attempts to isolate a pure species by following the methods of previous workers failed, and this fact led to the conclusion that the oxidation in these rice soils is due either to bacteria acting together in association or to a species distinct from the *B. Methanicus* of Söhngen.² Consequently the reaction was deemed worthy of closer investigation, particularly as Söhngen has shown in subsequent communications that *B. Pyocyanium* and other species possess the power of oxidizing methane and that *B. Pyocyanium*, *B. Fluorescens* and *M. Paraffinae* can oxidize such substances as benzene and kerosine. Stormer also states that *B. Hexacarbovorum* is capable of causing the oxidation in question.

The crude cultures referred to above develop readily in purely mineral culture liquids³ and when plated out in washed agar containing the same salts numerous colonies develop, but in no single instance were they found to possess the power of oxidizing methane. Attention was then turned to the use of silica jelly as a medium with the result that a pure species was isolated and studied.

¹ Harrison and Subramania Aiyer. *Mem. Dep. Agri., India, Chemical Series*, Vol. IV, No. 1.

² Söhngen. *Centl. Bakt.*, II Abt., XV (1905), p. 573.

³ Harrison and Subramania Aiyer. *loc. cit.*

Most of the usual methods of preparing silica jelly were employed, but as a whole they were found to be either cumbersome or unreliable, and it was not until a modification of Stevens and Temple's¹ method was adopted that success was readily attained. This method of preparing the medium was found to be easy and reliable and consequently it is described in full.

PREPARATION OF SILICA JELLY AND METHOD OF ISOLATION.

The method of Stevens and Temple produces a solution of silica which contains from 12 to 20 parts of sodium chloride (NaCl) per 1,000, but this concentration was found to exercise an inhibitory effect on the growth of the specific bacterium and any attempt to remove it by dialysis resulted in removing at the same time the traces of hydrochloric acid (HCl) which are necessary to prevent the solution from coagulating. This difficulty was obviated by carrying on the process of dialysis by means of distilled water containing 2—4 parts of $\frac{N}{2}$ HCl per 100 c.c. and a slightly acid solution of silica was thereby obtained entirely free from common salt. To this solution the requisite quantity of nutrient mineral salts was added to give a concentration of 1 gm. AmCl, 0.2 gm. MgSO₄, 0.5 gm. K₂HPO₄ and a trace of FeCl₃ per 1,000 c.c., the medium was placed in plugged tubes and sterilized in the autoclave at about 10 lb. pressure. The tubes thus prepared remained fluid for about a month.

When the sterile tubes of silica solution were required for plating purposes, they were first of all inoculated in the usual way and poured into sterile Petri dishes. To each dish was then added a quantity of sterile Na₂CO₃ solution sufficient to neutralize the free HCl present and the dish gently tilted so as thoroughly to mix the contents. The silica solution at once sets to a jelly so that the plates can be conveniently manipulated.

The methods adopted for the preparation of the crude cultures have been described in a previous publication² and these were plated out in the manner described and incubated in an atmosphere consisting of a mixture of methane and oxygen. Very small colonies developed at the end of 5-6 days which when placed in Botkin culture flasks containing mineral nutrient solution and filled with a mixture of methane and oxygen gave rise to a strong growth and brought about the oxidation of the former gas.

DESCRIPTION OF THE BACTERIUM.

The bacteria thus isolated were found to consist of a single species which grew quite well on all ordinary media and also on mineral agar, but in all these

¹ Stevens and Temple. *Centl. Bakt.*, Vol. XXI, p. 84.

² Harrison and Subramania Aiyer. *loc. cit.*

cases the growths obtained could not be induced to develop their specific reaction when inoculated into mineral nutrient solution entirely free from organic matter. The growth produced by inoculation from these cultures was very poor, but the introduction of *small traces* of peptone, starch, mannitol, gelatine, glucose, lactamide or sodium asparaginate to the mineral solution led to a strong growth without however causing more than a slight oxidation of the methane. Cultures of this type when plated out on silica jelly yielded no result and it became evident that the bacterium when in pure culture after contact with nutrient organic matter loses all power of oxidizing methane. Consequently it was impossible to complete the investigation by isolating in purely mineral media, transferring through organic media, and finally isolating again on mineral media before determining the oxidizing effect.

In these circumstances to make certain that the bacterium which oxidizes methane in a purely mineral environment is the same as the one whose cultural characteristics on organic media are herein described, was only possible by greatly increasing the number of definite and distinct observations. To this end many crude cultures have been prepared from different rice soils at different seasons of the year and plated out on silica plates. Well isolated colonies have been taken from the plates, tested for their power of oxidizing methane and studied when growing both on mineral and organic media. In all cases the results obtained have been identical and the bacteria isolated on mineral plates have always developed the same characteristics when grown on organic media and have then always lost the power of oxidizing methane. There can, therefore, be no reasonable doubt, but that we are dealing with one and the same bacterium.

The organism is an actively motile bacterium 2—4 μ long and 0.5 μ wide possessing a single (more rarely two) polar flagellum and is therefore classed as a pseudomonas. It is easily stained by all ordinary staining fluid but is *decolourized* by Gram's method. The cultural characteristics are as follows :—The surface colonies on agar are white, opalescent and spreading, but appear small and roundish in the depth. The surface gelatine colonies are slightly sunken owing to liquefaction taking place and in addition there is at first a local greenish-brown coloration which later permeates the whole mass of the gelatine producing a greenish fluorescence. This coloration is characteristic of the cultures on most organic media.

Gelatine stabs are characterized by a faint growth along the line of puncture and, in the course of 48 hours, the gelatine becomes liquefied with a slight sediment at the bottom of the liquid portion. The liquefaction is at first crateriform, then saccate, and finally it extends to the side of the tube and the greenish fluorescence becomes well developed. Agar streak cultures are at

first white and slimy but develop the greenish tint later and finally become brownish. The growth on potato is at first slight and brownish but afterwards spreads until the whole of the potato is discoloured. Bouillon is cloudy at first with a pellicle but the greenish tint develops later and no indol could be detected. There is a strong evolution of gas in nitrate bouillon and nitrate peptone in the course of 24 hours, whilst milk is peptonized and the surface covered with a pellicle. The colour of litmus milk is discharged. Slight acidity is produced in glucose, sucrose and lactose bouillon and the colour of the litmus is discharged.

These cultural characteristics agree entirely with those for *B. Fluorescens liquefaciens* as described by Lehmann and Neuman, and it is interesting to note that Söhngen¹ has shown this bacterium to be capable of oxidizing such hydrocarbons as benzene and paraffin and using them as an energy source when grown in a liquid mineral medium containing 1 per cent of hydrocarbon.

THE OXIDATION OF METHANE.

The method employed in measuring the oxidizing power of this bacterium was essentially the same as that used in similar experiments on the oxidation of hydrogen², the apparatus being shown in the annexed sketch.



The neck of a bottle is closed with a rubber cork through which a three-way glass stop-cock C passes, the exit tubes D and E of which are plugged with sterile cotton wool. About 30 c.c. of the nutrient solution are placed in the bottle, the cork and stop-cock inserted and the whole sterilized in the autoclave. The liquid is inoculated by momentarily removing the cork and the exit tube D is then connected to an air-pump and the inlet tube E to a reservoir containing the mixed gases experimented with.

The air is pumped out of the bottle until the liquid boils and gas is then admitted through E from the reservoir. This process is repeated three to four times until it is perfectly certain that the bottle is filled with the mixed gas and that there is no admixture with air.

After inoculation the bottles are first weighed and then stored under water and incubated at

¹ Söhngen. *Centl. Bakt.*, II Abt., XXXVII, pp. 595—609.

² Harrison and Subramania Aiyer. *Mem. Dep. Agri., India, Chem. Series*, Vol. IV, No. 4.

30°C. for about a fortnight. At the end of this period the bottle is wiped dry and again weighed so as to determine whether or not leakage has occurred. The tap C is then opened under water to allow the internal pressure to adjust itself and after bringing the surfaces of the internal liquid and external water to the same level, the tap C is closed, and the bottle wiped dry and again weighed.

Any difference in weight is equivalent to an alteration in the volume of the contained gas which is reduced to N. T. & P. both before and after the experiment. Finally the remaining gas is removed and analysed and any changes in composition which it has undergone noted. Knowing the composition and volume before and after the experiment it is possible to calculate the alteration in volume of the component gases.

This method has one disadvantage when applied in this particular instance in that the solubility of CO_2 in water causes the volume of the gas obtained after the reaction to be too low. This, however, does not affect materially the determination of the other gases present so that the disappearance of oxygen and methane is the real measure of the change.

A few typical experiments are quoted to show the kind of result obtained when under autotrophic conditions.

TABLE I.

Showing action under autotrophic conditions.

c. c. N. T. & P.

EXPERIMENT		No. I			No. II			No. III		
DAYS INCUBATION		14 DAYS			21 DAYS			8 MONTHS		
		Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO_2	...	1.7	9.0	+7.3	...	5.5	+5.5	...	7.5	+7.5
O	...	86.1	59.2	-26.9	57.7	39.4	-18.3	59.1	29.4	-29.7
CH_4	...	33.8	18.5	-15.3	29.4	19.1	-10.3	30.1	14.4	-15.7
N	...	26.9	27.6	+0.7	55.0	55.0	..	56.4	58.6	+2.2
TOTAL	...	148.5	114.3	-34.2	142.1	119.0	-23.1	145.6	109.9	-35.7

Considering the great variation in period of incubation between these experiments, it is evident that the reaction in pure culture does not reach completion, and it would appear probable that this is only attained under natural condition. It is also noticeable that the ratios $\frac{\text{CH}_4 \text{ Disappearing}}{\text{O Disappearing}}$, i.e.,

1/1.75, 1/2.06, 1/1.89, respectively, are not far removed from the theoretical ratio $\frac{1}{2}$ required by the equation :—



2 Vols. 4 Vols. = 2 Vols.

Hence it would appear that only very small amounts of C are assimilated under the experimental conditions, thus accounting for the non-completion of the reaction and also adding to the probability that this bacterium only reaches its maximum efficiency in mixed culture.

It has been stated previously that after the bacterium was allowed to grow on ordinary media or even on mineral agar, no growth could be induced in mineral nutrient solutions entirely devoid of organic matter. The organism would, however, grow quite vigorously when transferred from organic media to such mineral solutions containing traces of organic matter and experiments to test the CH_4 oxidation were conducted with solutions containing such substances as sodium asparaginate, peptone, starch, mannitol, glucose, lactamide, humus, etc. The results obtained are given in Table II.

TABLE II.

Showing the results obtained in presence of organic matter.

c. c. N. T. & P.

Substance added	0.03 PER CENT. SODIUM ASPARAGINATE			0.1 PER CENT. PEPTONE		
	Before	After	Diff.	Before	After	Diff.
CO	1.8	3.1	+1.3	0.2	3.8	+3.6
O	54.2	51.7	-2.5	60.2	48.9	-11.3
CH ₄	33.0	32.3	-0.7	25.1	24.7	-0.4
N	7.9	9.6	+1.7	12.4	13.1	+0.7
TOTAL	96.9	96.7	-0.2	97.9	90.5	-7.4

Substance added	0.03 PER CENT. PEPTONE			0.05 PER CENT. MANNITOL			0.05 PER CENT. STARCH		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂	0.7	1.3	+0.6	2.2	7.9	+5.7	2.0	1.7	-0.3
O	106.7	102.5	-4.2	92.9	84.4	-8.5	85.0	83.1	-1.9
CH ₄	54.9	54.3	-0.6	49.4	48.0	-1.4	45.2	45.0	-0.2
N	13.2	14.7	+1.5	10.9	13.0	+2.1	9.9	10.6	+0.7
TOTAL	175.5	172.8	-2.7	155.4	153.3	-2.1	142.1	140.4	-1.7

TABLE II.—*Concld.*

Substance added	0.05 PER CENT. HUMUS			0.05 PER CENT. GLUCOSE			MINERALS ONLY		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂ ...	2.0	1.4	-0.6	2.0	7.2	+5.2	0.2	...	-0.2
O ...	85.6	83.2	-2.4	86.5	78.5	-8.0	55.2	52.8	-2.4
CH ₄ ...	45.5	43.9	-1.6	46.0	45.8	-0.2	29.4	28.5	-0.9
N ...	10.0	13.9	+3.9	10.2	11.2	+1.0	6.3	6.9	+0.6
TOTAL ...	143.1	142.4	-0.7	144.7	142.7	-2.0	91.1	88.2	-2.9

The organism used in these experiments was obtained from an active culture in mineral media so that it is very evident that contact with organic matter practically inhibits the power of oxidizing methane and particularly in the presence of sugars the main action is one of oxidation of the organic matter in preference to methane. In several instances, however, there is an appreciable oxidation of methane and therefore it seemed probable that a reduction of the amount of organic matter below the quantities used would make this more apparent. The experiment was therefore varied by inoculating from an organic medium into a series of mineral nutrient solutions containing graduated amounts of glucose. The results obtained are shown in Table III.

TABLE III.

Showing effect of bacterium when transferred from an organic medium into solutions of glucose.
c. c. N. T. & P.

Glucose	0.5 PER CENT.			0.1 PER CENT.			0.05 PER CENT.		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂ ...	...	26.2	+26.2	...	11.0	+11.0	...	7.2	+7.2
O ...	96.3	66.8	-29.5	92.3	79.1	-13.2	101.1	92.4	-8.7
CH ₄ ...	30.2	29.9	-0.3	29.0	29.1	+0.1	31.8	30.9	-0.9
N ...	23.9	23.9	...	22.9	22.5	-0.4	25.1	25.3	+0.2
TOTAL ...	150.4	146.8	-3.6	144.2	141.7	-2.5	158.0	155.8	-2.2

Glucose	0.025 PER CENT.			0.01 PER CENT.			0.005 PER CENT.		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂ ...	...	3.1	+3.1	0.2	4.0	+3.8	0.9	1.1	+0.2
O ...	96.6	92.4	-4.2	52.3	39.7	-12.6	92.5	85.8	-6.7
CH ₄ ...	30.4	29.8	-0.6	24.2	19.0	-5.2	28.8	26.7	-2.1
N ...	24.0	23.7	-0.3	13.5	14.7	+1.2	29.4	30.5	+1.1
TOTAL ...	151.0	149.0	-2.0	90.2	77.4	-12.8	151.6	144.1	-7.5

TABLE III.—*Concl'd.*

		MINERALS ONLY		
		Before	After	Diff.
CO ₂	...	...	2.2	+2.2
O	...	97.7	94.8	-2.9
CH ₄	...	30.7	29.9	-0.8
N	...	24.3	24.4	+0.1
TOTAL	...	152.7	151.3	-1.4

It will be seen that practically no methane is oxidized, but comparatively large quantities of CO₂ are produced through the oxidation of glucose when the concentration of the latter is above 0.01 per cent., whereas with concentrations of 0.01 per cent. appreciable quantities of methane are oxidized. Below 0.01 per cent. the amount of methane oxidized diminishes, and in mineral solution only the amount becomes negligible. It would, therefore, appear that the power of oxidizing methane is dependent upon the power of any strain of the species to assimilate the carbon contained in the gas and that this in turn depends entirely upon the environment previously encountered.

SUMMARY.

1. The bacterium responsible for the oxidation of methane at the surface of the swamp paddy soils examined has been identified as *B. Fluorescens liquefaciens*.
2. The power of oxidizing considerable proportion of methane is only enjoyed so long as the bacterium is propagated on purely mineral media.
3. In the presence of much organic matter this power is reduced to a minimum and is not regained by further inoculation into purely mineral media. In the presence of traces of certain organic substances, the power is appreciable though low.

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THE GASES OF SWAMP RICE SOILS

PART VI

CARBON DIOXIDE AND HYDROGEN IN RELATION TO RICE SOILS

BY

W. H. HARRISON, D. Sc

Imperial Agricultural Chemist



AGRICULTURAL RESEARCH INSTITUTE, PUSA

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[Received for publication on 26th April, 1920.]

INTRODUCTORY.

THE study of the composition of paddy soil gases has demonstrated the fact that the main constituents are methane and nitrogen, and that carbon dioxide and hydrogen are found only in comparatively small quantities.¹ The proportion of hydrogen varies from nil to 12 per cent. but, in general, the value does not rise above 3 per cent. in soils carrying a crop, and is usually nil. The values are usually higher in uncropped soils than in cropped ones but the reason for this has been fully discussed in a previous publication.²

The proportion of carbon dioxide is also subject to wide variations but it is generally higher than that of hydrogen and is never non-existent. The values vary from about 2 per cent. up to, very occasionally, 20 per cent. but the average in cropped soils is about 5 per cent.

The gases which accumulate in paddy soils are mainly derived from the decomposition of organic matter present in the soil under anaerobic conditions by bacterial agencies.³ Practically all known decompositions of this type in pure culture are accompanied by a considerable evolution of carbon dioxide and hydrogen, and, except in the presence of nitrates and nitrites, the disengagement of nitrogen is inconsiderable. Even the fermentations resulting in the

¹ Harrison and Subramania Aiyer. *Mem. Dept. Agri., India, Chemical Series*, Vol. III, No. 3.

² *Ibid.*, Vol. IV, No. 1.

³ *Ibid.*, Vol. III, No. 3, and Vol. V, No. 1.

formation of methane have been shown to include the production of considerable proportions of carbon dioxide and hydrogen. This being the case it is a remarkable fact that paddy soil gases should contain such large proportions of CH_4 and N and such very small proportion of CO_2 and H. In the case of a fairly soluble gas like CO_2 this could possibly be accounted for by solution and consequent removal by the water draining through the soil, but this explanation would be very unsatisfactory when applied to the case of hydrogen. It is also very difficult to account for the presence of such a large proportion of nitrogen in view of the facts that the soil conditions preclude the formation of nitrates or nitrites, at least during the cultivation season, and that the source of much of this N has been shown to be the organic matter present in, or incorporated with, the soil.¹

Consequently, to account for the observed facts it is necessary to assume either (1) that the fermentation which takes place in paddy soils is of a different type to that generally observed with anaerobic fermentations and one which results in the production mainly of CH_4 and N with practically no CO_2 and H, or (2) that the fermentation is of a normal type, but that certain products, *e.g.*, CO_2 and H, are removed by secondary reactions leaving a residuum of CH_4 and N.

In regard to the accumulation of the considerable volume of nitrogen gas which has been demonstrated in these soils the latter alternative offers a very feasible explanation. No fermentation by pure bacterial cultures, with the exception of those connected with denitrification processes, has been shown to lead to the liberation of sufficient N to account for this fact, but, on the other hand, the presence of small quantities of N in the products has been observed frequently. Given then an ordinary mixed type of anaerobic fermentation combined with removal of the CO_2 and H by some secondary reaction, a residuum would be obtained containing mainly CH_4 and N. In cropped soils it has been shown that the CH_4 is gradually removed by oxidation process and the residual gas would therefore contain a very large proportion of nitrogen commensurate with that actually found in the gases obtained from cropped soils.

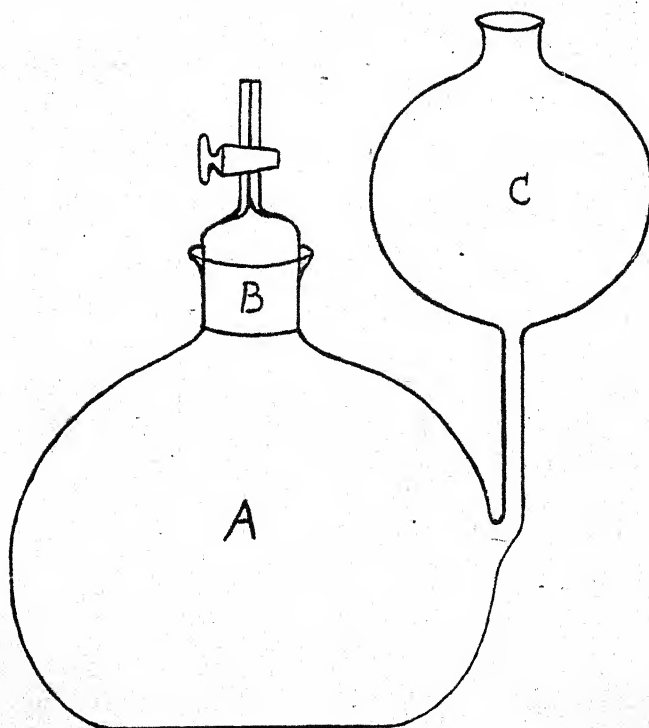
For the purpose of this investigation it was therefore necessary in the first instance to study the fermentation of green-leaf manure.

¹ Harrison and Subramania Aiyer. *Mem. Dept. Agri., India, Chemical Series*, Vol. V, No. 1.

PART I.

THE TYPE OF FERMENTATION OF ORGANIC MATTER INDUCED IN PADDY SOILS AND ITS GASEOUS PRODUCTS.

IN order to study the composition of the gases produced by the anaerobic fermentation of green-leaf manure the apparatus shown in the annexed sketch was employed, consisting of a flask A provided with a hollow ground-glass stopper B which terminates in a capillary exit tube closed with a glass tap. From the side of A a side-tube emerges and connects to the spherical reservoir C provided with a small open mouth closed by a plug of cotton wool. The



materials employed in the experiment were introduced into A, which was almost filled with water, and the whole sterilized. After inoculation sterile water was poured into C until A was completely filled and all air bubbles displaced. As a further precaution to ensure anaerobic conditions the surface of

the liquid in C was covered with a layer of kerosine. Any gas produced during fermentation accumulates in A and can be drawn off for examination at interval through the tap B without introducing air or disturbing the contents of the flask.

In the first series of experiments leaves of *Calotropis gigantea* were placed in the flask, together with the necessary water and, after sterilization in an autoclave, were inoculated by the addition of an emulsion of paddy soil, and the flask completely filled with water. The sterilization of the leaves ensured that no air remained in them. These experiments were repeated many times during a period extending over several years with uniform results and, consequently, it is only necessary to quote one series of results by way of illustration.

TABLE I.

Showing the composition of the gases obtained from sterile green-leaf manure inoculated with paddy soil.

Days	Volume of gas obtained c.c.	Rate of gas evolution c.c. per day	PERCENTAGE COMPOSITION			
			CO ₂	H	CH ₄	N
0-1	16.8	16.8	34.5	52.4	0.6	12.5
1-14	9.6	0.74	59.4	6.2	24.0	10.4
14-16	12.4	6.2	61.3	4.8	28.2	5.7
16-35	100.0	5.3	48.8	3.4	47.8	...
35-52	87.0	5.0	46.3	2.4	51.0	0.3
52-56	41.9	10.4	31.3	7.6	61.1	...

Thus, immediately, there is induced a rapid fermentation producing mainly CO₂ and H which, however, quickly subsides, and then the rate of gas production remains low for a considerable period of time. Subsequently a fairly rapid fermentation sets in producing mainly CO₂ and CH₄, the hydrogen being small in quantity and N practically non-existent. In the early stage the gas produced contains a relatively high proportion of nitrogen. This sequence of events was not only observed in all experiments of a similar character, but similar results were also obtained when inoculations were made into sterile leaves from flasks in active fermentation instead of using soil direct.

Experiments carried out with sterile leaves do not, however, approximate to field conditions and, consequently, a series was carried out with natural *unsterilized* leaves and soil. It was at once observed that the resulting fermentation was more intense but, notwithstanding this, the type—judged by the composition of the gases—remained the same and neither did the inclusion of fresh paddy roots produce any modification.

TABLE II.

Showing composition of gases obtained from unsterilized green-leaf manure inoculated with paddy soil.

Days	Volume of gas in c.c.	Rate of evolution per day	PERCENTAGE COMPOSITION			
			CO ₂	H	CH ₄	N
0-1	421	421	76.0	5.8	0.0	18.2
1-2	398	398	96.5	...	0.0	3.5
2-4	141	72	94.2	0.2	3.5	2.1
4-5	125	125	88.1	...	5.4	6.5
5-7	122.7	61	86.5	0.4	12.4	0.7
7-13	97	16	49.5	...	50.5	0.0

The increased intensity of the fermentation when using unsterilized leaf is not due to enzymic action as shown by the fact that the addition of toluene, etc., entirely inhibits gas production. In addition, inoculation from a flask in active fermentation into *sterile* green-manure reproduces the fermentation.

TABLE III.

Composition of gases obtained by inoculation of sterile green-leaf manure from an active fermentation.

Days	Volume of gas c.c.	Rate	PERCENTAGE COMPOSITION			
			CO ₂	H	CH ₄	N
0-3	27.9	9.3	95.0	.....	.....	5.0
3-5	20.6	10.3	96.2	.....	.....	3.8
5-6	19.9	19.9	93.0	.....	4.0	3.0
6-7	30.6	30.6	81.4	3.7	8.8	6.1
7-8	37.0	37.0	81.4	1.8	13.2	0.6
8-9	19.0	19.0	82.2	2.1	14.7	1.0
9-10	19.4	19.4	79.9	2.6	16.5	1.0
10-13	74.8	24.9	63.6	3.1	23.1	10.2
13-14	51.4	51.4	61.2	10.9	28.0	trace
14-15	44.3	44.3	54.8	.... 45.4	.....	nil
15-17	11.4	5.7	37.7	0.0	62.3	0
17-19	33.2	16.6	23.5	0.0	76.5	0
19-21	52.0	26.0	20.0	5.5	74.5	0
21-23	22.0	11.0	14.5	0.3	85.2	0
23-24	44.3	44.3	16.9	4.5	78.6	0
24-26	49.0	24.5	15.7	17.5	66.8	0

These fermentations take place under very artificial conditions and it is very probable that under natural conditions the proportion of the disengaged gases varies from those obtained. Nevertheless, it appears to be permissible to draw the following general conclusions:—

- (a) The addition of green-leaf manure to paddy soils gives rise to a strong fermentation resulting in the liberation of CO₂ and H and N

- (b) This fermentation rapidly decreases in intensity and is replaced by a fermentation which liberates mainly CO_2 and CH_4 .
- (c) The fermentation is of a bacterial nature as shown by the fact that it is inhibited by the presence of toluene.

It was easily demonstrated that the first fermentation is due to specific bacteria by plating out on nutrient agar and inoculating the colonies into tubes of sterile green-leaf manure provided with gas tubes. A strong fermentation was induced by bacteria belonging to two distinct types.

Type I. Motile, sporing bacteria stained by Gram's method and which liquefy gelatine. Strong growth on potato with, occasionally, the production of gas; acid produced but no gas in glucose and lactose media; milk slightly acid but no coagulation; nitrates not reduced and indol not produced.

Type II are non-motile, non-sporing bacteria unstained by Gram's stain and give a dry, crumpled brown growth on potato. Indol produced.

Type I induced a very active fermentation when inoculated into flasks containing green-leaf manure, the gases produced consisting mainly of CO_2 and H together with appreciable quantities of N. Type II produces a much less intense fermentation and the proportion of N liberated is higher. Both fermentations cease within 96 hours.

TABLE IV.

Showing volume and composition of gases produced by type bacteria under similar conditions.

Type	Volume of gases in 96 hours	PERCENTAGE COMPOSITION			
		CO_2	H	CH_4	N
I a	288	27.9	67.7	...	4.4
I b	192	22.5	75.2	...	2.3
II a	33	16.7	65.3	...	18.0
II b	46	23.5	68.2	...	6.7

These organisms are closely related so far as their activities lie in bringing about of fermentation of green-manure. They induce a rapid fermentation resulting in the production of CO_2 and H together with some nitrogen, but they do not bring about a disintegration of the leaf and appear to confine their activities to intercellular substances and their action soon ceases. They may be looked upon as being responsible for the first stage of the decomposition of green-manures in paddy soils and to pave the way for the main fermentation, which is associated with the production of methane.

This second fermentation occurs, *i.e.*, the methane fermentation, when the residuum from the first fermentation is allowed to stand for some time, but is much more rapidly induced if this residuum is sterilized and then re-inoculated with fresh paddy soil. Thus within six days from the initiation of the fermentation 162 c.c. of gas were collected, containing 30.6 per cent. CO_2 , 4.5 per cent. H_2 , 60.4 per cent. CH_4 and 4.5 per cent. N_2 .

Considerable difficulty was experienced in establishing this fermentation in synthetic media but, ultimately, active cultures were obtained in solutions of calcium butyrate and lactate and also with filter paper. In all cases the gas produced had a similar composition to that shown above.

PART II.

THE RELATIONSHIP OF CO₂ AND H TO PADDY SOILS.

The study of the fermentation of green-leaf manure shows that under anaerobic conditions such as obtain in swamp paddy soils there is the production of considerable volumes of CO₂, H, CH₄ and only a small proportion of N, whereas the gases which accumulate in the soil have been shown to consist mainly of N and CH₄ with practically no CO₂ and H and, in fact, in cropped soils the N preponderates.

The disappearance of the large volumes of CO₂ and H may be explained (a) by solution of the CO₂ in, and removal with, the water draining through the soil and (b) by the oxidation of the H in a manner analogous to that of the CH₄ by the surface film, but, even if these explanations are accepted, it is difficult to reconcile them with the low values found for these substances in the soil gases. Some other additional explanation is necessary and the only feasible one appeared to be that the CO₂ and H are recombined under the action of agencies existing in the soil, or that the reduction of the CO₂ by H provided energy for bacterial activities.

To test this hypothesis 10 grams of soil and 25 c.c. of water were sealed up in tubes containing a mixture of CO₂ and H. At the end of seven days the tubes were opened over mercury and the residual gases measured and analysed :—

TABLE V.
Showing disappearance of CO₂ and N when sealed up with paddy soil and water.
c.c. N. T. & P.

Constituent	EXPERIMENT I			EXPERIMENT II		
	Before	After	Diff.	Before	After	Diff.
CO ₂	51.4	29.0	-22.4	205	105	-100
H	251.0	65.2	-185.8	131	31.7	-99.3

There was a strong bacterial development in the tube and it was found possible to carry the reaction through a series of transfer inoculated into the following solution :—

		Per cent.
K ₂ HPO ₄	.. ..	0.05
MgSO ₄	.. ..	0.02

			Per cent.
NH ₄ Cl	..	..	0.10
NaHCO ₃	..	..	0.05
traces of CaSO ₄ , MnCl ₂ and FeCl ₃			

In all cases the production of large proportion of sulphuretted hydrogen was noticeable and consequently, under the experimental conditions, much of the loss of hydrogen was due to sulphate reduction.

TABLE VI.
Showing the production of sulphuretted hydrogen.
c. c. N. T. & P.

Constituent	Before	After	Diff.
CO ₂	151.5	41.4	-72.5
H	182.0	100.8	-81.2
SH ₂	nil	73.61	+73.61

A parallel series of experiments carried out with CO₂ only, and also with a mixture of CO₂ and CH₄, gave no indication of absorption and, consequently, the reaction only takes place in the presence of hydrogen. This would show that CO₂ and H cannot persist in admixture in paddy soils and that their disappearance is bound up with the metabolism of the sulphur bacteria.

The presence of sulphate is, however, not essential to the reaction as is shown by inoculation and transfer inoculations into the following solution which is devoid of sulphate:—

			Per cent.
K ₂ HPO ₄	..	..	0.05
MgCl ₂	..	..	0.02
NH ₄ Cl	..	..	0.10
NaHCO ₃	..	..	0.05
traces of CaCl ₂ , MnCl ₂ and Fe ₂ Cl ₆			

TABLE VII.
Showing disappearance of CO₂ and H in the absence of sulphates.
c. c. N. T. & P.

Constituent	EXPERIMENT I. CRUDE CULTURE 4 DAYS' INOCULATION			EXPERIMENT II CRUDE CULTURE 9 DAYS' INOCULATION		
	Before	After	Diff.	Before	After	Diff.
CO ₂	52.2	31.1	-21.1	47.8	7.6	-40.2
H	89.6	63.6	-26.0	81.9	nil	-81.9
N	4.6	4.6	0.0	4.1	5.2	+1.1

The disappearance of the CO_2 and H is, therefore, not necessarily associated with sulphate reduction but is also due to reduction of the CO_2 and on the assumption that the carbon is assimilated by the organisms the reaction would form an energy source :—

$2\text{H}_2 + \text{CO}_2 + \text{aq} = \text{C} + 2\text{H}_2\text{O} + \text{aq} \dots + 34 \text{ Cals.}$ In this reaction the ratio $\frac{\text{Vol. CO}_2}{\text{Vol. H}} = \frac{1}{2}$ and consequently the measurement of the ratio between the disappearing gases will give some idea of the correctness of this view.

Determination of Ratio $\frac{\text{CO}_2}{\text{H}}$. In Table VII the ratios for experiments I and II are $\frac{1}{1.3}$ and $\frac{1}{2.0}$ respectively, and show no agreement. In fact from a large number of experiments carried out it was found that the ratio was far from constant and values varying up to almost $\frac{1}{4}$ were obtained. The early experiments were carried out in the manner described in a previous publication,¹ and the variations were at first ascribed to errors of experiment, but 'blank' tests carried out showed that the method of experiment was accurate to less than 2 per cent. Consequently some other explanation must be sought for. This was found in the fact that, coincident with the disappearance of CO_2 and H_2 , there were formed varying proportions of CH_4 , and that when the proportion of the latter was low the ratio was under $\frac{1}{2}$, and that where it was high the ratio was about $\frac{1}{3}$ to under $\frac{1}{4}$.

Three examples are given in the following Table :—

TABLE VIII.
Showing variations in the ratio $\frac{\text{CO}_2}{\text{H}}$.
c. c. N. T. & P.

Constituent	EXPERIMENT I			EXPERIMENT II			EXPERIMENT III		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO_2	60.4	45.4	-15.0	123.7	93.8	-29.9	121.7	102.0	-19.7
H	73.4	49.4	-24.0	68.2	12.1	-56.1	67.1	nil	-67.1
CH_4	nil	nil	nil	nil	3.5	+3.5	nil	12.7	+12.7
N	4.9	4.3	-0.6	4.2	7.5	+3.3	3.9	5.4	+1.5
Ratio $\frac{\text{CO}_2}{\text{H}}$	Ratio = $\frac{1}{1.6}$			Ratio = $\frac{1}{1.9}$			Ratio = $\frac{1}{3.5}$		

¹ Harrison and Subramania Aiyer. *Mem. Dept. Agri., India. Chemical Series*, Vol. IV, No. 4.

It is therefore evident that the reaction which leads to the disappearance of the CO_2 and H is one of reduction of the former, and it is also evident that it is not a simple reaction, but rather one compounded of two distinct reactions, *e.g.*, one resulting solely in the formation of organic matter and the other resulting in the formation of organic matter together with the production of CH_4 .

The rate at which the mixed gas disappears. With the later experiments a method was adopted which permitted the changes in volume to be followed continuously. The apparatus used is shown in the annexed sketch.

A few c.c. of an active culture, or 1 gram of soil, and a few c.c. of the mineral nutrient solution are introduced into the wide-mouthed bottle A which is closed with the india-rubber stopper B carrying two glass tubes C and D. The tube C is closed with a stop-cock and serves as the entry-tube for the mixed gas. The exit tube D is connected by means of a mercury sealed rubber joint to a longer piece of tube E which dips into a basin of mercury and serves as a manometer. The mixture of gases is passed through the bottle A until all air is displaced and the stop-cock then closed, but as the gas in A is under excess pressure equilibrium with the external air is obtained by momentarily opening and closing the stop-cock. The bottle is immersed in a larger vessel F filled with water which was generally surrounded by a thick felt jacket in order to exclude the light. As the reaction progressed the mercury rose in the tube E and the height is a measure of the change in volume of the gases in A. The residual gases were removed by running mercury into A by the tube C and then analysed. The following Table gives some of the results obtained taking the original volume as 100 in each case—all values being corrected to N. T. and P.

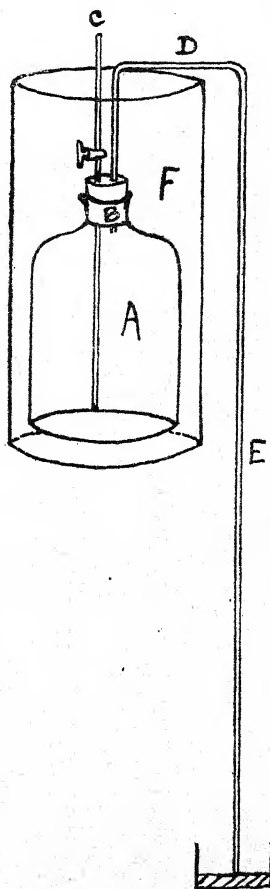


TABLE IX.

Day	EXPERIMENT I Paddy soil in the light	EXPERIMENT II. Paddy soil in the dark	EXPERIMENT III Made from active culture in the dark
0	100	100	100
1st	...	98.9	98.6
2nd	...	98.1	96.0
3rd	97.6	97.0	94.2
4th	97.6	..	89.1
5th	97.5	...	80.8
6th	...	95.7	69.0
7th	...	...	58.4
8th	...	93.0	47.8
9th	97.1	92.2	44.0
10th	...	91.0	44.0
11th	96.0	87.2	44.0
12th	...	84.1	Refilled with gas mixture 101
13th	93.8	79.2	98.0
14th	...	65.2	91.7
15th	90.5	...	85.8
16th	...	56.8	72.2
17th	88.9	49.3	65.8
18th	...	45.4	59.8
19th	87.0	44.7	53.0
20th	...	44.5	46.8
21st	83.2	44.5	43.1
22nd	81.0	44.5	42.7
30th	72.3		
40th	61.9		
50th	54.5		
63rd	46.0		

In all the above experiments the gaseous mixture was approximately 50 per cent. CO_2 and 50 per cent. H_2 and 'blank' sterile experiments were also carried out which showed no absorption. All three experiments agree in showing that the absorption is small until the growth is well established and then the rate of absorption is extremely rapid. The effect of light in retarding the reaction is also well brought out in Experiment I and it is also clearly shown that inoculation from an active culture establishes the reaction quicker than does inoculation with paddy soil.

It is quite clear that once the reaction is started it proceeds at a fairly uniform rate until it suddenly ceases. On again passing a fresh supply of gas into the bottle the reaction recommences and proceeds as before and again ceases when the same degree of absorption has approximately been reached. This procedure can be repeated several times with similar results and indicates clearly that the exhaustion of one or other of the constituent gases determines the point at which absorption ceases.

SUMMARY AND GENERAL CONCLUSIONS.

1. No evidence has been obtained to show that the fermentation of green-manure under anaerobic conditions takes an abnormal or unusual course. The gaseous products of this fermentation appear to be carbon dioxide, hydrogen, methane, and a small proportion of nitrogen.

2. The absence of the CO_2 and H from paddy soil gases is accounted for by the fact that a subsidiary bacterial action takes place resulting in the reduction of the CO_2 by the hydrogen and the formation of organic matter and even marsh gas. *CO_2 and H cannot as a matter of fact persist in association in paddy soils.*

3. The proportion of CO_2 to H which disappears in this reaction varies from 1 : 1.5 to 1 : 3.5 according to the proportion of marsh gas produced, so that much more H disappears than CO_2 . On the other hand, the evidence obtained in this investigation goes to show that more CO_2 is produced than H, so that one would naturally expect more CO_2 than H to be generally present in paddy soil gases. This is in accordance with previously observed facts.

4. This reaction between CO_2 and H is beneficial to the paddy crop in several ways. In the first place, the amount of free H in the soil gases is kept at a very low value and consequently the amount of this gas which reaches the surface film is negligible. It has been shown previously that the surface film is capable of oxidizing H, and if large quantities of H reached it they would be oxidized at the expense of oxygen which would otherwise be available for root aeration. On the other hand, any excess of CO_2 in the soil gases would be decomposed with the liberation of oxygen immediately it came in contact with the surface film. *The reaction is, therefore, an important factor in the conservation of the oxygen available for root aeration.*

In the second place, the formation of marsh gas is of extreme importance by increasing the supply of that substance to the surface film and thereby also increasing the oxygen supply in the manner indicated in a previous publication. It is also permissible to assume that the organic matter also produced during the reaction is sooner or later subjected to a similar fermentation with similar results, so that there is a complicated carbon cycle in these soils which results in the conservation of the carbon and ensures the maximum amount being converted into methane with a correspondingly increased efficiency of root aeration. *This reaction is, therefore, mainly concerned with the conservation of carbonaceous matter and its utilization so as to produce the maximum amount of root aeration.*

Thirdly, by keeping the carbon dioxide content of the soil gases at a minimum the efficiency of the aeration of the roots is proportionately increased.

Finally, this reaction permits of a rational explanation of the liberation of nitrogen gas without having to call in the aid of a peculiar and undemonstrated fermentation of nitrogenous organic matter. The facts now put forward show that there is taking place continually in these soils a resolution of organic matter followed by a recombination and at each turn of the cycle small quantities of nitrogen are liberated. In the aggregate, during a cropping season, the volume of nitrogen thus liberated will assume large proportions, and consequently *the liberation of gaseous nitrogen in paddy soils is the resultant of the complicated carbon cycle and not of any specific bacterial fermentation.*

5. This reaction has been studied in relation to paddy soils, but it would appear to be by no means specific to such soils. The same reaction has been obtained when a Pusa soil, which has never been subjected to wet cultivation, was substituted for the paddy soil in the experiments. It would, therefore, appear probable that the active agents producing this reaction are widely diffused and become operative when the conditions become favourable. In effect, much which has been ascribed to a specific methane fermentation, *e.g.*, in marsh land, sewage, septic tanks, etc., would rather appear to be due to this reaction.

THE RETENTION OF SOLUBLE PHOSPHATES IN CALCAREOUS AND NON- CALCAREOUS SOILS.

BY

W. H. HARRISON, D.Sc.,
Imperial Agricultural Chemist ;

and

SURENDRALAL DAS, M.Sc.,
Assistant to the Imperial Agricultural Chemist.

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INTRODUCTION.

THE manner in which the phosphoric acid of superphosphate is absorbed and retained by soils has been the subject of considerable investigation in past years and has given rise to considerable controversy. Storer¹ defines the mode of action of superphosphate as follows :— “ When a superphosphate is applied to the soil, the first rainfall, or even the moisture of the soil, dissolves the soluble phosphoric acid, and causes it to soak into the earth. There it comes in contact with carbonate of lime, and with compounds of iron and alumina, and is arrested by these substances. That is to say, the phosphoric acid is precipitated in the earth in the form of phosphate of lime for the most part at first, and of the still more difficultly soluble phosphates of iron and alumina. Unless, indeed, the soil is actually deficient in lime, it is not to be supposed that much of any of the soluble phosphoric acid can remain dissolved in the soil water longer than a few days at the utmost.” Again, “ It is to be observed that, although the phosphoric acid which has been made soluble with toil and trouble is speedily reprecipitated in the earth, and that although some of the phosphoric acid may eventually be changed then to difficultly soluble forms, the precipitate is nevertheless exceedingly finely divided and very thoroughly disseminated.

¹ “ Agriculture in some of its relations with Chemistry,” 1897, Vol. I, pp. 364 & 370.

It is far finer than the finest bone-dust; and, what is still more important, it is distributed everywhere in the soil. The roots of the crop are thus provided with a continuous supply of phosphoric acid.....”.

The above may be taken as representing the generally accepted view at that time regarding the rôle of superphosphate, and was based upon the observations of several investigators on the rate of reaction between superphosphate solutions and calcium carbonate, and also upon the completeness of the absorption of the soluble phosphoric acid by various soils, particularly those containing a large proportion of carbonate of lime.¹

Evidence, however, soon accumulated which tended to show that this simple explanation did not entirely agree with observed facts, and it appeared probable that a certain proportion of the absorption could be explained on other than purely chemical grounds. Schroeder,² experimenting with intimate mixtures of superphosphate and chalk made into a thick paste, showed that the rate of reversion of the soluble phosphate into insoluble form was exceedingly quick, but that in similar mixtures of soil and superphosphate the fixation was extremely slow and much phosphoric acid remained in solution at the end of 20 days. These two series are, however, not comparable because, in the case of the soils, the amount of superphosphate present was more than sufficient to decompose the whole of the CaCO_3 present and still leave an excess in solution, whereas in the former series the reverse conditions held. This experiment cannot be said to have disproved the possibility of retention through the formation of insoluble compounds, but, on the other hand, it points to the existence of another form of absorption when the possibility of the formation of such compounds is removed.

The observation of Pagoul³ that phosphoric acid was absorbed by soils from solutions of potassium phosphate lent support to an alternative explanation, and this was not only confirmed by the percolation experiments of Schreiner and Failyer⁴ but, in addition, they showed that the absorption was subject to laws capable of mathematical expression of a type which indicated the process to be of a physical character. Prescott,⁵ later, has shown that the reaction between soil and phosphates obeys the laws of adsorption, but he observes that the phosphate must be kept in solution by using another acid, thus eliminating all possibility of the formation of insoluble calcium phosphates. The

¹ “Agriculture in some of its relations with Chemistry,” 1897, Vol. I, p. 364, *et. seq.*

² *J. Landw.*, XL, No. 3, p. 213.

³ *Abst. Expt. Stat. Record*, VI, p. 118.

⁴ *U.S.A. Dept. Agri. Bureau of Soils Bull.* 32.

⁵ *Jour. Agri. Sci.*, VIII, p. 111.

investigations of Russell and Prescott¹ on the extraction of soils by acid solvents have confirmed the fact that phosphoric acid is adsorbed by soils, but here again the possible influence of calcium carbonate is necessarily removed.

Regarding the possibility of CaCO_3 materially affecting the course of the retention of phosphates Pratolongo² has shown that there may be two distinct processes at work. With soils containing no lime the absorption of phosphoric acid from mono-calcic phosphate solution is practically instantaneous, but with a soil containing much CaCO_3 there is a further slow fixation of P_2O_5 after initial absorption.

From the preceding it will be seen that the retention of phosphoric acid by soils is by no means capable of a satisfactory explanation on purely chemical grounds, and that, in all probability, the phenomenon of adsorption is an important factor. Adsorption is an instantaneous process and, consequently, under conditions which obviate any possibility of the formation of insoluble compounds, may be looked upon as the factor governing the range of distribution of the phosphoric acid through the soil and the availability of the retained phosphate. On the other hand, the introduction of a secondary factor such as the formation of insoluble calcium phosphates must considerably modify the result, but the magnitude of this modification must depend to a large extent upon the rapidity of the reaction concerned. It is conceivable that if, for instance, the rate of the reaction between mono-calcic phosphate and calcium carbonate is very rapid, the range of distribution through a soil will be limited. Conversely, given a very slow rate of reaction the distribution will be wider. Evidence on this point is conflicting, and it is impossible to formulate with any degree of certainty the probable course of events in highly calcareous soils such as are found in Bihar and other portions of the Gangetic system. Consequently, it appeared desirable to institute an investigation to determine, if possible, the predominating factors governing the distribution of soluble phosphates through calcareous and non-calcareous soils, and the results of this investigation form the subject matter of this Memoir.

The enquiry has resolved itself into three distinct divisions, viz :—

- (1) A study of reaction between mono- and di-calcic phosphates and carbonate of lime.
- (2) A determination of the factors governing the retention of soluble phosphates in calcareous and non-calcareous soils.
- (3) The distribution of soluble phosphates through calcareous and non-calcareous soils.

¹ *Jour. Agri. Sci.*, VIII, p. 65.

² *Le Staz. Sper. Agri.*, 1915, XLVIII, p. 457.

PART I. THE REACTION BETWEEN CALCIUM CARBONATE AND MONO- AND DI-CALCIC PHOSPHATES.

THE importance the reaction between CaCO_3 and superphosphate bears in relation to the chemistry of soils was early recognized and has been the subject of considerable study, but, as previously pointed out, the conclusions obtained have been of a very contradictory nature. Meyer¹ digested 10 grams of superphosphate with 300 c.c. water, and added 45 grams of precipitated CaCO_3 to the clear filtrate. The mixture was shaken at frequent intervals and tested to determine how much phosphoric acid remained in solution. He found that at the end of six hours 92 per cent. remained in solution, in 24 hours 80 per cent., in 8 days 12 per cent., and in 24 days 2.4 per cent., and concluded that the phosphoric acid of superphosphate is only slowly reverted. Schroeder,² however, obtained results which showed a much more rapid reaction, for, at the end of one day only, 4 per cent. remained in solution, and 67 per cent. was present in the citrate-soluble form and 28 per cent. in the insoluble form. Confirmation of this was obtained by Stoklasa,³ who showed that, by mixing the ingredients in proper proportions, either di- or tri-calcic phosphate could be produced. Davis,⁴ on the other hand, concludes from experiments made by him that the soluble P_2O_5 of superphosphate does not attack CaCO_3 , even when the two are boiled together.

In view of these widely divergent statements it was felt that, as a preliminary, a detailed study of the reaction involved should be made, and this was undertaken in two stages: (a) The reaction between mono-calcic phosphate and CaCO_3 , and (b) the reaction between di-calcic phosphate and CaCO_3 .

A. SUPERPHOSPHATE IN RELATION TO CALCIUM CARBONATE.

One gram of CaCO_3 was shaken with 100 c.c. of a solution of monocalcium phosphate for 24 hours, the P_2O_5 present in solution being

¹ Storer. "Agriculture in some of its relations with Chemistry," Vol. I, p. 365.

² *Loc. cit.*

³ *Landw. Ver. Stat.*, XLII, No. 6, p. 439.

⁴ *Agri. Jour. India*, 1917, XII, p. 265.

determined before and after. The experimental values are given in Table I.

TABLE I.

Showing the extent to which the P_2O_5 of mono-calcic phosphate is reverted on shaking a solution with $CaCO_3$.

Expt. No.	P_2O_5 in solution before shaking	P_2O_5 in solution after shaking	P_2O_5 removed	Per cent. removed
1	0.4851	0.0113	0.4738	97.7
2	0.4939	0.0115	0.4824	97.7

The removal of P_2O_5 from solution was therefore approximately complete. Further experiments of a similar type were carried out in which the shaking occupied shorter intervals of time.

TABLE II.

Showing the extent to which solutions of mono-calcic-phosphate are reverted when shaken with $CaCO_3$ for varying intervals of time.

Expt. No.	Time of shaking	P_2O_5 taken	P_2O_5 left	P_2O_5 removed	Per cent. removed
1	1 hour	0.5680	0.0079	0.5601	98.61
2	2 hours	0.5680	0.0084	0.5596	98.52
3	4 hours	0.5680	0.0060	0.5620	98.94

Consequently it will be seen that the reaction between $CaCO_3$ and super-phosphate solutions is a very rapid one and results in practically all the P_2O_5 being rendered insoluble.

The amount of P_2O_5 left in solution is practically constant and of a much higher value than the solubility of tri-calcic phosphate, and leads to the conclusion that, under the conditions of the experiment, the compound formed is of a

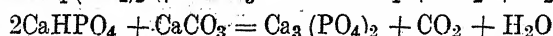
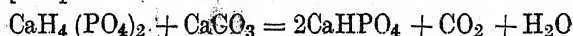
more soluble type. Confirmation of this is obtained by *boiling* one gram of CaCO_3 with 100 c.c. of superphosphate solution, when it is found that the precipitation is more complete than at ordinary temperatures.

TABLE III.

Showing the effect of boiling solutions of mono-calcic phosphate with CaCO_3 .

Expt. No.	P_2O_5 before	P_2O_5 after	P_2O_5 removed	Per cent. removed
1	0.4851	0.0002	0.4849	99.96
2	0.4939	0.0011	0.4928	99.78

Under these conditions the reaction becomes practically complete and the amount of P_2O_5 remaining in solution becomes very small. It would, therefore, appear probable that the reaction results in the formation of di-calcic phosphate in the first instance, and then, at the higher temperature, of tri-calcic phosphate:—



This conclusion is capable of being rigorously tested by determining the amount of CO_2 evolved at ordinary temperatures and at the boiling temperature.

Taking the latter condition first, 0.5 gram of mono-calcic phosphate (94 per cent. purity) was boiled with 0.5 gram of CaCO_3 and 75 c.c. water, and the CO_2 evolved absorbed by soda-lime after taking the usual precautions. 0.1514 gram of CO_2 was obtained, whereas theory demanded 0.1650 gram if tri-calcic phosphate were formed, and 0.0825 gram if the di-calcic were formed.

In a second experiment 0.5 gram of calcium biphosphate (pure, Baird & Tatlock, London) containing 56.8 per cent. P_2O_5 was treated as described above and yielded 0.1653 gram CO_2 as against the theoretical 0.1746 gram and 0.0873 gram respectively.

Consequently at boiling temperatures the reaction proceeds to completion with the formation of tri-calcic phosphate.

For the estimation of the CO_2 evolved at ordinary temperatures Hall's¹ apparatus was employed. 15 c.c. of a solution of mono-calcic phosphate,

¹ *J.C.S.*, 1902, LXXI, p. 81.

containing 0.0311 gram of P_2O_5 in solution, were introduced into the reaction bulb of the apparatus into which $CaCO_3$ had been previously introduced. The whole was gently agitated until the manometer reading became constant, and then the tap connecting the secondary bulb was opened and the pressure again read. From the readings obtained the amount of CO_2 evolved was calculated according to the formula given by Hall. The temperature during the experiments was $28^\circ-29^\circ C$.

Two duplicate experiments were carried out, and it was found that in one case 5.28 c.c. of CO_2 and in the other 5.91 c.c. were evolved, whilst the theoretical amount required for the formation of di-calcic phosphate from 0.0311 gram P_2O_5 was 4.9 c.c. *Consequently at ordinary temperatures the main product is di-calcic phosphate together with small quantities of tri-calcic phosphate.*

The excess CO_2 over the theoretical was 0.38 c.c. in Experiment I and 1.01 in Experiment II, and, as 44 grams or 22400 c.c. CO_2 represent 142.08 grams P_2O_5 transformed from di- to tri-calcic phosphate, it follows that 0.00241 gram P_2O_5 in Experiment I and 0.00641 gram in Experiment II were fully reverted. *That is, from 7.7 to 20.6 per cent. of the P_2O_5 reverts to tri-calcic phosphate.*

This observation was confirmed by direct analysis, *i.e.*, by the estimation of the di-calcic phosphate produced. It will be shown later that to do this with any pretence to accuracy the extraction with a standard solution of ammonium citrate must be done in the *cold*, otherwise a reaction between $CaCO_3$ and the dissolved phosphate takes place, tri-calcic phosphate being formed and low values for citrate-soluble P_2O_5 obtained.

Experiment I. One hundred c.c. of a solution of mono-calcic phosphate containing 0.5743 gram P_2O_5 were shaken with 1 gram $CaCO_3$ for 24 hours. At the end of that time the insoluble portion was filtered and, after *air-drying*, was extracted in the cold with 100 c.c. of ammonium citrate of sp. gr. 1.09, and the P_2O_5 present as $CaHPO_4$ determined.

P_2O_5 originally present	..	..	..	..	0.5743 gram
P_2O_5 left in solution ..	..	..	..	..	0.0034 "
P_2O_5 reverted	..	..	..	..	0.5709 "
P_2O_5 extracted by ammonium citrate	..	..	..	..	0.5521 "
P_2O_5 present as $Ca_3(PO_4)_2$	..	..	..	..	0.0188 "

∴ 3.27 per cent. of the P_2O_5 was converted into $Ca_3(PO_4)_2$.

Experiment II. Four grams mono-calcic phosphate were shaken with 5 grams CaCO_3 and 200 c.c. water for 24 hours and the insoluble residue extracted *twice* with cold ammonium citrate solution.

P_2O_5 originally present	..	..	..	..	2.2860 grams
P_2O_5 left in solution ..	..	..	..	..	0.0086 gram
P_2O_5 reverted	..	..	..	..	2.2774 grams
P_2O_5 1st extraction	1.3850				
P_2O_5 2nd ..	0.4181				
					1.8031 ..
P_2O_5 as $\text{Ca}_3(\text{PO}_4)_2$ ..	..	..	..	..	0.4743 gram
.. 20.75 per cent. of the P_2O_5 had reverted to tri-calcic phosphate.					

These results are confirmatory of the ones obtained by measuring the amount of CO_2 evolved during the reaction, and it may therefore be taken that, under the experimental conditions, the reaction between CaCO_3 and mono-calcic phosphate is a very rapid one and results primarily in the formation of di-calcic phosphate. There then follows a secondary reaction between the di-calcic phosphate and CaCO_3 resulting in the formation of a certain proportion of tri-calcic phosphate. Consequently an investigation of the factors which affect the rate of complete reversion to the latter compound must include a study of the reaction between di-calcic phosphate and CaCO_3 .

B. DI-CALCIC PHOSPHATE IN RELATION TO CALCIUM CARBONATE.

The solubility of di-calcic phosphate, although small, is still very appreciable, as one litre of pure water dissolves 0.136 gram at 25°C ., and one litre of saturated CO_2 solution 0.561 gram. It, therefore, follows that the final stage of the retention is a reaction between a comparatively insoluble substance and CaCO_3 which will necessarily depend upon the rate at which the former can be brought into solution.

The reaction between CaCO_3 and *dissolved* CaHPO_4 is very rapid and complete as is shown by the following experiment:—

Two hundred c.c. of a solution of CaHPO_4 containing 0.018 gram P_2O_5 were shaken for 24 hours with 1 gram CaCO_3 , and, at the end of that period, it was found that only 0.0005 gram P_2O_5 remained in solution, *i.e.*, 97 per cent. of the P_2O_5 had been rendered insoluble.

This being the case, the problem resolves itself into a study of the rate at which CaHPO_4 changes into $\text{Ca}_3(\text{PO}_4)_2$ under different conditions. In order

to do this a method of analysis was needed which would differentiate between di- and tri-calcic phosphates, and recourse was had to the well-known ammonium citrate method.

The results obtained in the earlier experiments were very irregular and discordant in character, and this appeared to be due to a reaction taking place between the di-calcic phosphate which had dissolved in the citrate solution and any CaCO_3 which might be present. In order to test this, 100 c.c. of a saturated solution of di-calcic phosphate in 1 per cent. ammonium citrate solution were shaken with 1 gram CaCO_3 for 24 hours, and the P_2O_5 in solution determined before and after. The original amount present was 0.1244 gram and this was reduced to 0.0908 gram showing a reversion of 27 per cent. Consequently it would appear probable that the standard method of extracting at 65°C . with a solution of ammonium citrate of sp. gr. 1.09 would be liable to error if CaCO_3 were present at the same time. This was actually found to be the case.

On the other hand, no indication of any reaction occurring was obtained when a solution of di-calcic phosphate in standard strength ammonium citrate was shaken *in the cold* for 24 hours with CaCO_3 . The actual values for the P_2O_5 in solution were 0.5310 gram originally and 0.5433 gram at the end. Consequently in all the experiments now considered the determination of di-calcic phosphate present was carried out by extraction with a *cold* solution of ammonium citrate of sp. gr. 1.09.

Reaction between di-calcic phosphate and CaCO_3 at 100°C . 1.0 gram of di-calcic phosphate, 1.0 gram CaCO_3 , and 100 c.c. of water were boiled together for periods varying from 15–45 minutes, and the CO_2 liberated determined.

TABLE IV.

Showing the amount of CO_2 evolved when 1 gram of di-calcic phosphate and 1 gram of CaCO_3 are boiled together with 100 c.c. water.

Experiment	Time of boiling	CO_2 gram evolved
1	15 minutes	0.1102
2	30 Do.	0.1138
3	45 Do.	0.1104
	Average	0.1115

The di-calcic phosphate employed contained 85.9 per cent. of the pure salt when estimated by the ammonium citrate method, and consequently the theoretical amount of CO_2 to be expected according to the equation $2\text{CaHPO}_4 + \text{CaCO}_3 = \text{Ca}_3(\text{PO}_4)_2 + \text{CO}_2 + \text{H}_2\text{O}$ is 0.1098 gram. The values actually obtained are slightly in excess of this but are sufficiently near (+ 0.0017 gram) to show that at high temperatures the reaction proceeds rapidly to a conclusion.

Reaction in the cold. Although the reaction is very rapid and complete at elevated temperatures, it appeared probable that at ordinary temperatures it would be a comparatively slow process. This was confirmed as follows:—

One gram of di-calcic phosphate containing 0.4134 gram of P_2O_5 was shaken with 100 c.c. water and 1 gram CaCO_3 . Five separate experiments were conducted in which the period of shaking was for 1, 2, 4, 8, and 16 days respectively. At the end of these several periods a determination of the P_2O_5 in solution, the P_2O_5 present as CaHPO_4 , and the amount present as $\text{Ca}_3(\text{PO}_4)_2$ was made. The results obtained are given in the following table.

TABLE V.

Showing the extent to which di-calcic phosphate reacts with CaCO_3 when shaken together in the presence of water for varying periods of time.

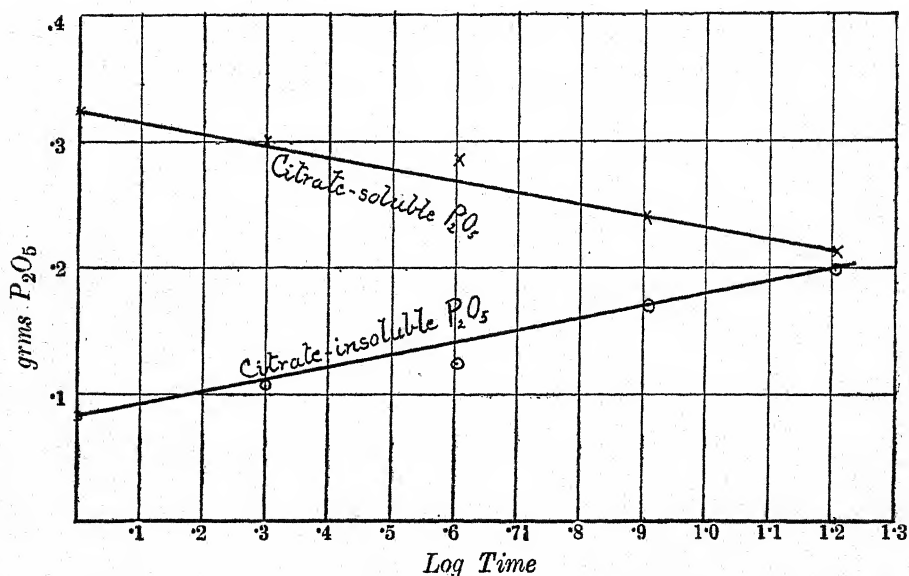
Time of shaking in days (T)	P_2O_5 in solution (W)	P_2O_5 citrate- soluble (D)	P_2O_5 citrate- insoluble (R)	% P_2O_5 reverted to $\text{Ca}_3(\text{PO}_4)_2$
1	0.0066	0.3246	0.0822	20
2	0.0059	0.2999	0.1076	26
4	0.0034	0.2858	0.1242	30
8	0.0033	0.2399	0.1702	41
16	0.0028	0.2117	0.1989	48
16	0.0341	0.3669	0.0124	Blank experiment. No CaCO_3 present.

The presence of a slow progressive reaction is thus demonstrated and, moreover, it is one which proceeds in a well defined manner. It is also noticeable that the amount of P_2O_5 present in solution is much below the normal amount as given by the "blank" experiment and decreases with the period of time.

The relationship between the amount of citrate-soluble P_2O_5 (D) or citrate-insoluble P_2O_5 (R) and the time (T) is a simple semi-logarithmic one as shown by plotting the values of D and R against the log of the time, when the curve produced is a straight line.

DIAGRAM I.

Showing the graph obtained when the amounts of citrate-soluble and citrate-insoluble P_2O_5 are plotted against log time.



Consequently the relationships may be expressed by the general formulæ—

$$\log T = A R - K,$$

$$\text{and } \log T = k - aD,$$

where A, a, K and k are constants. Employing the values $A=10.31$, $K=0.84$, $a=10.66$, and $k=3.464$, the calculated and the experimental values are shown in the following table.

TABLE VI.

Containing the calculated and the experimental values for the reversion of di-calcic phosphate.

T	R found	R calculated	Error	D found	D calculated	Error
1	0.0822	0.0815	+ 0.0007	0.3246	0.3253	- 0.0007
2	0.1076	0.1107	- 0.0031	0.2999	0.2970	+ 0.0029
4	0.1242	0.1399	- 0.0157	0.2858	0.2687	+ 0.0171
8	0.1702	0.1690	+ 0.0012	0.2399	0.2404	- 0.0005
16	0.1989	0.1982	+ 0.0007	0.2117	0.2122	- 0.0005

From the relationship $\log T = AR - K$ it follows that under the experimental conditions $R = 0.0815 + 0.097 \log T$, and consequently the velocity of the reaction $= \frac{dR}{dT} = 0.097 T^{-1}$ and the acceleration is $\frac{d^2R}{dT^2} = -0.097 T^{-2}$ i. e., the velocity of the reaction is in inverse proportion to the time and the acceleration is negative and in inverse proportion to (time).² The reaction is, therefore, strongly retarded and can only reach completion at the end of a considerable period of time. This conclusion emerges when there is continuous and intimate contact between the whole mass of the reacting bodies, and it is therefore justifiable to conclude that the conversion of di-calcic into tri-calcic phosphate must proceed at a much slower rate under the conditions which obtain in the soil.

The reaction is in reality one of the formation of tri-calcic phosphate; and in this connection the amount of soluble phosphate present at any moment is of extreme importance. The experimental values obtained clearly show that these values decrease as the reaction progresses, and it is possible to deduce from the relationships previously indicated that

$$W = C - kR,$$

where W = amount of P_2O_5 in solution,

R = amount of P_2O_5 in the citrate-insoluble form,

and C and k are constants.

Taking $C = 0.0093$ and $k = 0.032$ the experimental and the calculated values are contrasted in the following table.

TABLE VII.

Contrasting the experimental and the calculated values for the P_2O_5 in solution (W) when di-calcic phosphate is shaken with $CaCO_3$ and water for varying periods of time.

Time	W calculated	W found	Error
1	0.0067	0.0066	- 0.0001
2	0.0059	0.0059	0.0000
4	0.0053	0.0034	- 0.0019
8	0.0039	0.0033	- 0.0006
16	0.0030	0.0028	- 0.0002

This relationship is of the utmost importance, for it means that the amount of P_2O_5 present in solution decreases in proportion to the formation of tri-calcic phosphate, and this notwithstanding the fact that there is always more than sufficient di-calcic phosphate present to maintain a saturated solution of that substance. The P_2O_5 corresponding to a saturated solution under the experimental conditions is given by the "blank" experiment as 0.0341 gram per 100 c.c. but, in the presence of $CaCO_3$, the values obtained are only 0.0028 to 0.0066 gram, thus showing that the amount in solution is not determined by the di-calcic phosphate present. What determines the actual value is the point to which the reaction has progressed, *i.e.* the amount of $Ca_3(PO_4)_2$ formed, but it is impossible to consider that a very insoluble body of this type can have any direct effect, and this is negatived by the fact that the value of S is not constant. The conclusion is forced that some other product of the reaction is the determining cause. The reaction may be formulated as follows,—

$2CaHPO_4 + CaCO_3 = Ca_3(PO_4)_2 + H_2O + CO_2$, and consequently the only other product which can affect the values of S in proportion to the progress of the reaction is the amount of CO_2 produced, but this substance alone would increase the values rather than lower them. The presence of $CaCO_3$, however, materially alters the conditions in that it reacts with the CO_2 forming soluble bicarbonate, thus introducing calcium ions into the solution which would tend to reduce the proportion of P_2O_5 in solution. Under the experimental conditions the CO_2 produced does not escape and, consequently, as the reaction progresses, more and more calcium ions are brought into solution, thus proportionately lowering the amount of dissolved P_2O_5 present.

This brings at once into prominence the relationship between the CO_2 present in the soil gases and the amount of P_2O_5 present in the soil solution. Leather¹ has shown that the soil gases in Pusa soils contain very appreciable amounts of this constituent and, further, that with a very small partial pressure for the CO_2 quite appreciable amounts of CaCO_3 go into solution. Consequently calcareous soils,—on the basis of the experimental results now put forward,—will contain a much lower value of P_2O_5 , all other things being equal, in the soil solution than in the case of non-calcareous soils. This conclusion was also reached by Leather from the treatment of soils with water, CaCO_3 and CO_2 , but unfortunately he quotes no experimental data in support.

The above experiments on the rate of reversion of CaHPO_4 were carried out by the shaking method in a comparatively large volume of water, and do not approximate to soil conditions where the CaCO_3 and di-calcic phosphate are static and where the volume and rate of movement of the water is comparatively small. It seemed very probable that under these conditions the rate of reversion would be considerably reduced, and experiments were carried out to test this.

A mixture of 1 gram di-calcic phosphate containing 0.4134 gram P_2O_5 , and 1 gram CaCO_3 , was made into a paste with 4 c.c. water and stored in test tubes which were sealed so as to be air-tight, and at the end of varying periods of time the contents were examined.

TABLE VIII.

Showing the extent to which reversion occurs in a paste composed of di-calcic phosphate and CaCO_3 over varying periods of time.

Time in days	Citrate-soluble P_2O_5 (D)	Citrate-insoluble P_2O_5 (R)	Per cent. reverted
1	0.3934	0.0200	5
2	0.3704	0.0430	10
4	0.3599	0.0535	13
8	0.3316	0.0818	20
16	0.2946	0.1188	29
16	0.4022	0.0112	2.7
Blank experiment. No CaCO_3 present.			

¹ Leather, J. W. "Soil Gases." *Mem. Dept. Agri. India, Chemical Series*, Vol. IV, No. 3. "The System Water, Calcium Carbonate, and Carbonic Acid." *Ibid.*, Vol. I, No. 7.

Under these conditions the amount of reverted P_2O_5 present at the end of 16 days amounts to only 29 per cent. as against 48 per cent. obtained previously, thus demonstrating the fact that *in situ* in soil the rate of reaction is slower.

When the values for citrate-soluble P_2O_5 (D) and citrate-insoluble P_2O_5 (R) are plotted against the logarithm of the time, the resultant graph is a straight line. Consequently the reaction, under these new conditions, is of the same type as that obtained by the shaking method, the only difference being that the velocity is $\frac{2}{3}$ that of the latter. Here, again, the time necessary for the reaction to reach completion is very considerable.

In both of these experiments the CO_2 produced by the reaction does not escape and so has a marked effect on the velocity. In soil the tendency is for the CO_2 to diffuse away and, consequently, if the above conclusions are correct, the rate of reversion would be materially increased.

To test this point, two tubes were taken, each containing 1 gram $CaHPO_4$ ($=0.4143$ gram P_2O_5), 1 gram $CaCO_3$, and 4 c.c. of water. One tube was sealed up and the other was kept in vacuum over water. In the former 0.1241 gram was reverted, and in the latter 0.1629 gram.

The conclusions derived from a consideration of the foregoing experimental results may be briefly stated as follows:—

1. The reaction between calcium carbonate and mono-calcic phosphate at ordinary temperatures is a very rapid one resulting in the formation of di-calcic phosphate together with small quantities of tri-calcic phosphate.

2. Di-calcic phosphate *when present in solution* also rapidly reacts with calcium carbonate to form tri-calcic phosphate. The reaction between solid di-calcic phosphate and $CaCO_3$ in the presence of water is, however, much slower in character, and a considerable period of time is necessary for its completion.

3. During the course of the reaction CO_2 is produced which, by increasing the number of calcium ions in solution, reduces very materially the quantity of P_2O_5 formed in solution. Consequently, with calcareous soils the importance of cultural conditions which will tend to keep the CO_2 content of the soil gases at a minimum and thus permit of a greater concentration of P_2O_5 in the soil solution is apparent.

4. Assuming that the P_2O_5 of superphosphate may be retained in soils both by adsorption and by chemical combination, the rapidity of the reaction with $CaCO_3$ would lead to the conclusion that the retention in calcareous soils will be determined mainly by the latter factor.

PART II. THE FACTORS GOVERNING THE RETENTION OF SOLUBLE PHOSPHATES IN CALCAREOUS AND NON-CALCAREOUS SOILS.

IN Part I it has been demonstrated that the rate of reaction between solutions of mono-calcic phosphate and CaCO_3 is a very rapid one resulting in the formation of the comparatively insoluble di-calcic phosphate. The latter in turn slowly reacts with further quantities of CaCO_3 forming tri-calcic phosphate. Consequently it would appear probable that this reaction must play a prominent part in calcareous soils in retaining those forms of soluble phosphates which are capable of reacting, but, on the other hand, the effect of this chemical retention would be at a minimum in non-calcareous soils, and in these circumstances adsorption may be the determining factor.

It is of the utmost importance to determine which of these modes of retention is the predominant factor in the two types of soil, for not only must the "availability" of the retained phosphoric acid be very dissimilar in the two cases, but the distribution through the mass of the soil must also be very different.

With this object in view parallel series of experiments were carried out with a Pusa soil representing highly calcareous soils, and a soil from Kalianpur which is almost devoid of lime.

The chemical and physical composition of these soils is contrasted in the following table.

TABLE IX.
Giving chemical and physical composition of Pusa and Kalianpur soils.

Constituents				Kalianpur soil	Pusa soil
A. CHEMICAL COMPOSITION					
Sand and insoluble matter	..	..	..	86.36	56.40
Al_2O_3	..	..	..	4.04	2.80
Fe_2O_3	..	..	..	3.23	2.70
Mn_2O_4	..	..	..	0.04	0.07
CaO}	..	..	..	0.81	18.30
MgO}	..	..	..	1.14	1.65
K_2O}	..	..	..	0.69	0.51
Na_2O}	..	..	..	0.29	0.19
P_2O_5	..	..	..	0.38	0.11
SO_3	..	..	..	0.03	0.02
CO_2	..	..	..	0.13	14.33
Moisture	..	..	..	1.26	0.87
Organic matter	..	..	..	1.60	2.05
Total	..	..	..	100.00	100.00

TABLE IX.—*concl'd.*

Constituents				Kalianpur soil	Pusa soil
A. CHEMICAL COMPOSITION— <i>Concl'd.</i>					
N	..	..	..	0.018	0.067
Humus	..	..	..	1.15	1.00
Available K ₂ O	..	..	..	0.0344	0.0109
Available P ₂ O ₅	..	..	..	0.3237	0.0003
CO ₂ =CaCO ₃	..	..	..	0.284	32.57
B. MECHANICAL ANALYSIS					
Fine gravel	..	..	..	40.06	19.64
Sand	..	..	..	32.70	45.83
Fine sand	..	..	..	7.61	16.50
Silt	..	..	..	6.87	9.43
Fine silt	..	..	..	10.74	7.60
Clay	..	..	..	2.02	1.00
Total	..	..	..	100.00	100.00

Following the usual method of experiment for the recognition of adsorption, 100 grams of soil were shaken for one hour with one litre of water containing varying concentrations, within very wide limits, of soluble P₂O₅ derived from mono-calcium phosphate. At the end of this period the soil was separated from the solution by suction filtration and the concentration of the P₂O₅ remaining in solution determined.

Unfortunately no means were available for the maintenance of a rigorously controlled temperature, but this difficulty was surmounted to a considerable extent by carrying out all the experiments with the one soil at the same time, and under the same conditions, in a room which was not subjected to sudden changes of temperature. Notwithstanding small irregularities induced by slight differences in the conditions between one vessel and another the results obtained were very concordant.

Where adsorption phenomenon occurs, the distribution of a dissolved substance between the solvent and the adsorbing medium is regulated according to the expression,—

$$\frac{r}{m} = K S^{\frac{1}{p}},$$

where $\frac{r}{m}$ = amount of substance removed from solution (retained) per unit mass of adsorbent (soil),

S=concentration of the substance in the solvent *after* adsorption has taken place,
and K and p are constants.

For the sake of uniformity in contrasting the experimental results this expression may be written—

$$R = K S^{\frac{1}{p}}$$

where R=m.gr. of substance retained per 1000 grams soil,
and S=m.gr. of substance per 1000 c.c. solvent.

Then $\log R = k + \frac{1}{p} \log S$, where $k = \log K$.

Consequently if the distribution of the dissolved substance between the solution and the soil obeys the adsorption laws, the curve obtained by plotting the values of $\log R$ against $\log S$ is a straight line. This is the test mainly relied upon by us in interpreting the results obtained.

The data obtained in the series of experiments where 100 grams of soil were shaken with 1000 c.c. of solution are as follows:—

TABLE X.

Showing distribution of P_2O_5 as superphosphate between soil and solution using 100 grams soil and 1000 c.c. solution.

(m.gr. P_2O_5 .)

A. KALIANPUR SOIL

P_2O_5 originally in solution	P_2O_5 in solution after shaking	P_2O_5 retained by soil	S	R
4	2.8	1.2	2.8	12
16	10.5	5.5	10.5	55
64	41.5	22.5	41.5	225
256	174.7	81.3	174.7	813
1024	749.7	274.3	749.7	2743

TABLE X.—*concl.*

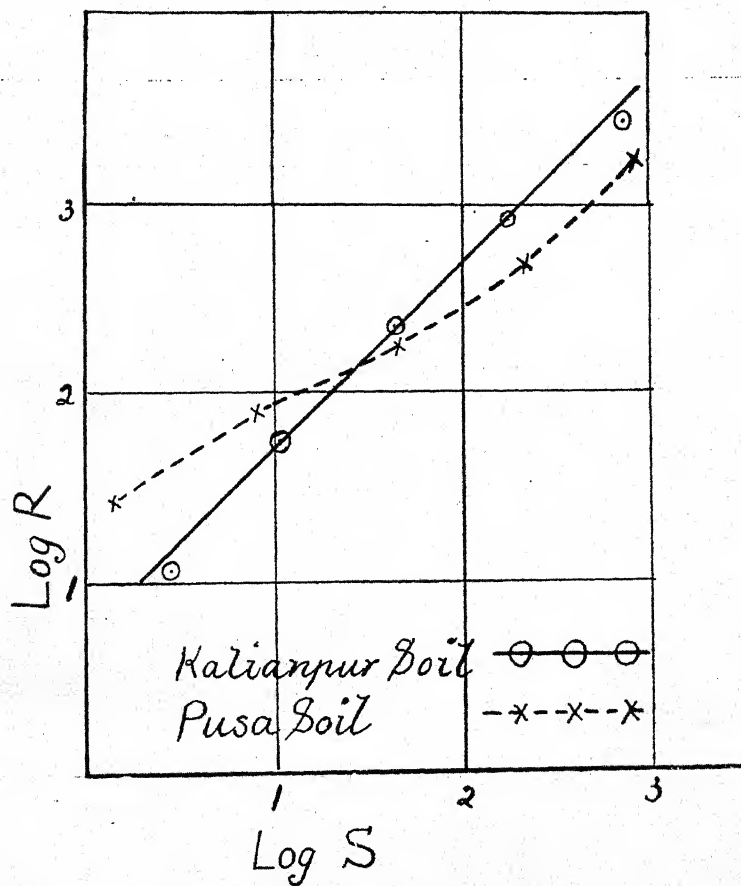
B. PUSA SOIL

P_2O_5 originally in solution	P_2O_5 in solution after shaking	P_2O_5 retained by soil	S	R
4	1.4	2.6	1.4	26
16	8.1	7.9	8.1	79
64	46.8	17.2	46.8	172
256	209.0	47.0	209.0	470
1024	859.1	164.9	859.1	1649

The logarithmic curves obtained by plotting $\log R$ against $\log S$ are shown in Diagram II.

DIAGRAM II.

Showing curves obtained by plotting $\log R$ against $\log S$.



It will be seen that the values for the Kalianpur soil fall upon a straight line, whereas those for the Pusa soil are on a well defined sinuous curve. It is, therefore, permissible to conclude that, under the experimental conditions, the P_2O_5 of superphosphate is mainly retained through adsorption in non-calcareous soils, whereas the retention is mainly due to other causes in the case of calcareous soils.

In order to obtain confirmation of these conclusions a second series of experiments were carried out in which 250 grams of soil were shaken with 1 litre of solution. The experimental conditions were similar to the preceding and the results are given in Table XI.

TABLE XI.

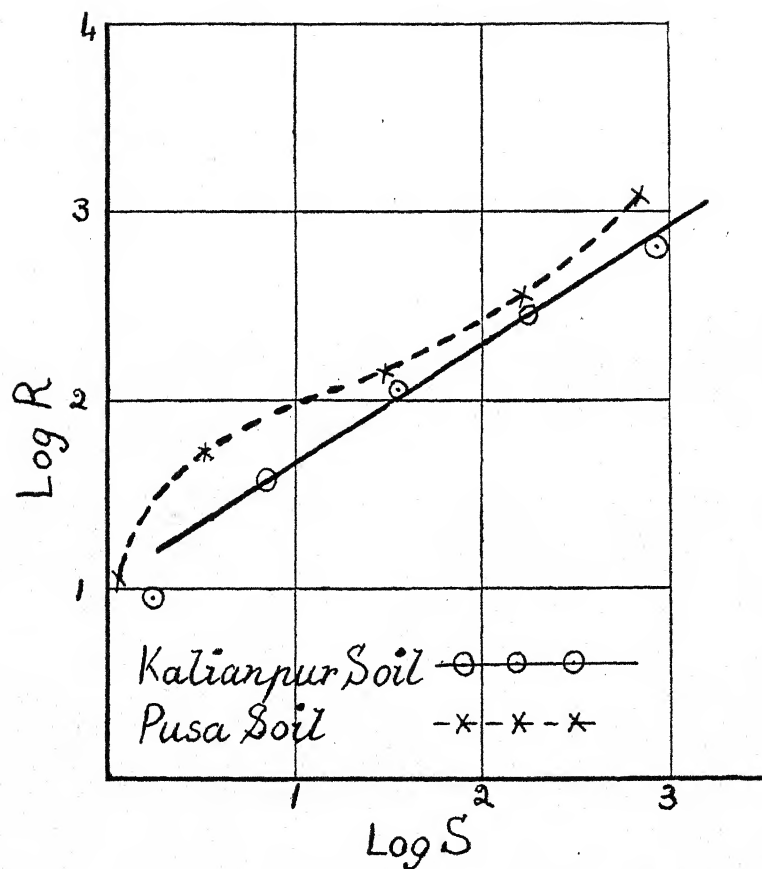
Showing distribution of P_2O_5 from superphosphate between soil and solution using 250 grams soil and 1000 c.c. solution.
(m.gr. P_2O_5 .)

P_2O_5 originally in solution	P_2O_5 remaining in solution	P_2O_5 retained by soil	S	R
A: KALIANPUR SOIL				
4	1.8	2.2	1.8	8.8
16	6.6	9.4	6.6	37.6
64	35.5	28.5	35.5	114.0
256	187.0	69.0	187.0	276.0
1024	864.4	159.6	864.4	638.4
B: PUSA SOIL				
4	1.2	2.8	1.2	11.2
16	3.2	12.8	3.2	51.2
64	29.6	34.4	29.6	137.6
256	167.6	88.4	167.6	353.6
1024	718.0	306.0	718.0	1224.0

The logarithmic curves obtained from the values of S and R are shown in Diagram III.

DIAGRAM III.

Showing curves obtained by plotting $\log R$ against $\log S$.



These results confirm the ones previously considered and support the conclusion that in non-calcareous soils the retention of the P_2O_5 is mainly due to adsorption, whereas in calcareous soils retention by adsorption is either non-existent or entirely masked by other causes.

Support to the conclusion that retention of superphosphate by calcareous soils is due to chemical combination is derived from experiments made by agitating the type soils with solutions of di- and tri-sodium phosphates, where in all cases the retention obeys the adsorption laws. In this case no chemical reaction could be demonstrated between $CaCO_3$ and the sodium phosphates.

Taking the adsorption from di-sodium phosphate first, 250 grams of soil were agitated for one hour with one litre of solutions of varying concentration and the P_2O_5 remaining in solution was then determined. The following results were obtained:—

TABLE XII.

Showing distribution of P_2O_5 between soil and solvent when di-sodium phosphate is used.

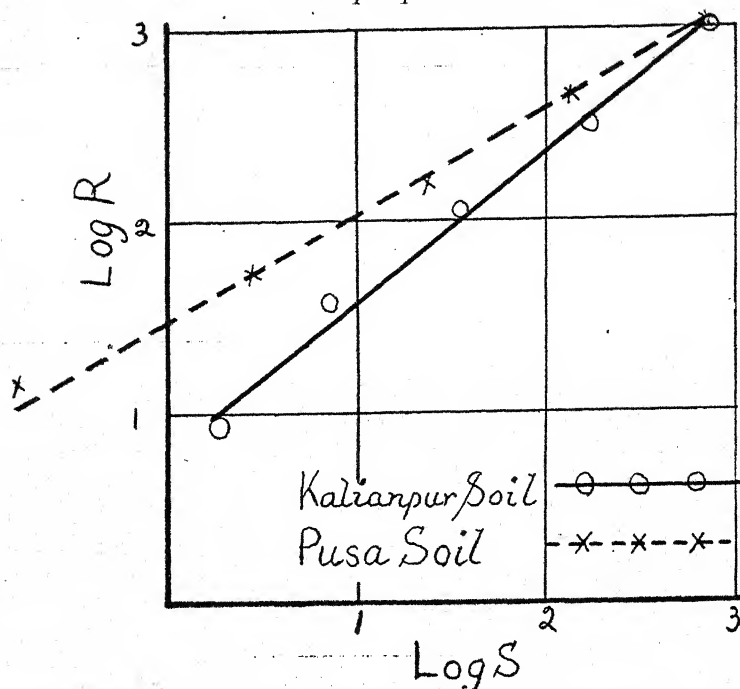
(m.gr. P_2O_5).

P_2O_5 originally present	P_2O_5 remaining in solution	P_2O_5 retained by soil	S	R
A. KALIANPUR SOIL				
4	1.9	2.1	1.9	8.4
16	6.6	9.4	6.6	37.6
64	35.6	28.4	35.6	113.6
256	178.2	77.8	178.2	311.2
1024	770.9	253.1	770.9	1012.4
B. PUSA SOIL				
4	0.16	3.84	0.16	15.36
16	2.7	13.3	2.7	53.2
64	24.3	39.7	24.3	158.8
256	140.2	115.8	140.2	463.2
1024	732.1	291.9	732.1	1167.6

The curves obtained by plotting log R against log S are shown in Diagram IV.

DIAGRAM IV.

Showing curves produced by plotting $\log R$ against $\log S$ when di-sodium phosphate is used.



It follows therefore that di-sodium phosphate is retained in both calcareous and non-calcareous soils by adsorption.

A similar experiment with tri-sodium phosphate and 200 grams soil gave the following results.

TABLE XIII.

Showing distribution of P_2O_5 between soil and solvent when tri-sodium phosphate is used.
(m.gr. P_2O_5 .)

A. KALLIANPUR SOIL

P_2O_5 originally in solution	P_2O_5 remaining in solution	P_2O_5 retained by soil	S	R
16	7.8	8.2	7.8	41.0
64	35.3	28.7	35.3	143.5
128	90.9	37.1	90.9	185.5
256	170.2	85.8	170.2	429.0
512	352.8	159.2	352.8	796.0
1024	735.6	288.4	735.6	1442.0

TABLE XIII.—*concl'd.*

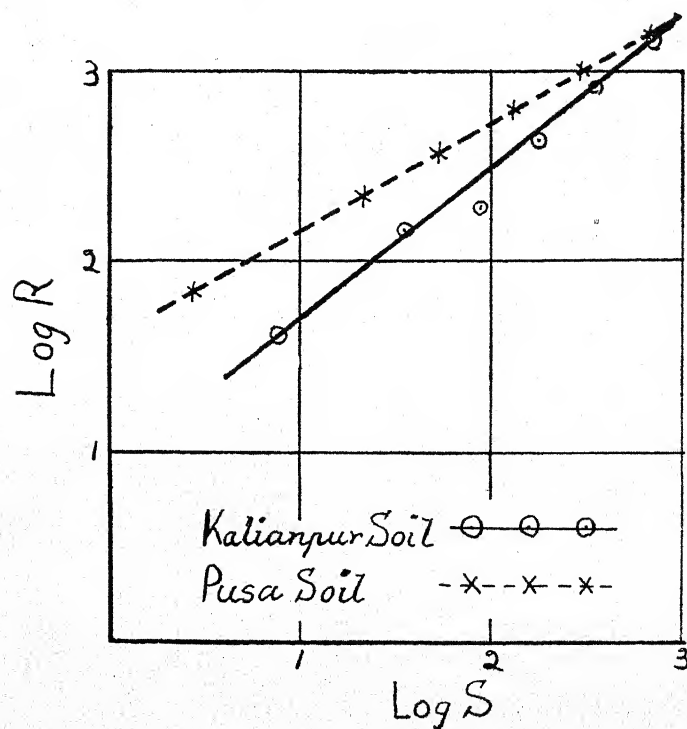
B. PUSA SOIL

P_2O_5 originally in solution	P_2O_5 remaining in solution	P_2O_5 retained by soil	S	R
16	2.8	13.2	2.8	66.0
64	21.5	42.5	21.5	212.5
128	52.9	75.1	52.9	375.5
256	130.5	125.5	130.5	627.5
512	305.2	206.8	305.2	1034.0
1024	709.1	314.9	709.1	1574.5

The curves obtained by plotting $\log R$ against $\log S$ are shown in Diagram V. In both cases the points lie on straight lines showing that the retention is due to adsorption.

DIAGRAM V.

Showing curves produced on plotting $\log R$ against $\log S$ when tri-sodium phosphate is used.



It may, therefore, be concluded that soluble phosphates which do not readily react with calcium carbonate are retained through adsorption in both calcareous and non-calcareous soils.

SUMMARY.

1. Soluble phosphates which do not react with CaCO_3 are retained by adsorption in both calcareous and non-calcareous soils.

2. Soluble phosphates of the type of mono-calcic phosphate which readily react with CaCO_3 are retained through adsorption in non-calcareous soils. In calcareous soils, on the other hand, the experimental values obtained show that other factors than adsorption come into play.

PART III. THE DISTRIBUTION OF SOLUBLE PHOSPHATES THROUGH CALCAREOUS AND NON-CALCAREOUS SOILS.

It has been shown in the preceding section that in non-calcareous soils the retention of the P_2O_5 of superphosphate is due to adsorption, whereas in calcareous soils other factors come into play which are probably due to chemical combination. The experimental evidence hitherto adduced is insufficient to determine if chemical factors are the ones which mainly determine the retention in the latter type of soil, or whether the phenomenon of adsorption has still an important bearing on the question.

When the rapidity of the reaction between superphosphate and calcium carbonate is taken into account, it is impossible to throw aside the hypothesis that this reaction must be the determining factor under circumstances in which it can occur and, if this is correct, then it would appear that when superphosphate is applied to a calcareous soil, comparatively insoluble calcium phosphates are immediately formed *in situ*, thus limiting the distribution of the P_2O_5 through the soil and causing the superphosphate to have a very localized value. On the other hand, in non-calcareous soils, as the retained P_2O_5 is a function of the P_2O_5 remaining in solution, it would appear probable that the range of action would be wider and the distribution more uniform throughout the mass of the soil.

In order to test the validity of these conclusions the following experiments were carried out. A solution of superphosphate (about 1 per cent. strength) was allowed to percolate through columns of the type soils of 20 inches depth contained in glass tubes, the bottom of which was closed by a fine wire gauze. After all the solution had passed into the column of soil the whole was allowed to stand for a further period of about 3 days until percolation ceased. The tube was then cut into 2" sections and the soil in each section removed and rapidly washed on the filter pump with a small quantity of water so as to remove the solution. The amount of P_2O_5 contained in the solution was then determined. The washed soil was rapidly dried, gently ignited to remove organic matter and the total P_2O_5 contained estimated. The difference between this value and the original one for the soil gives the amount of P_2O_5 retained by the soil in that section. The object in view in adopting this procedure was to obtain, if possible, an approximate idea of the proportion of P_2O_5 retained by each section of soil to the P_2O_5 in the soil solution. In the case of the Kalianpur soil, where adsorption is the determining factor, the relation at best could only be

very approximate, but it was hoped that more accurate data would be forthcoming in the case of the Pusa soil. Unfortunately, for the completion of each series there was involved a total of twenty-one separate determinations, and it was found that the sum of the P_2O_5 in the soil solution, the P_2O_5 present in the percolate, and the P_2O_5 retained by the soil did not equal the amount of P_2O_5 originally taken. This error varied from $7\frac{1}{2}$ to 17 per cent. and, although a large part of it was due to the accumulated errors of many separate determinations, yet a portion was probably due to the formation of very insoluble compounds as shown by experiments in which the tubes were cut and only the total P_2O_5 held in each section determined. In the latter series the error was reduced from $3\frac{1}{2}$ to $9\frac{1}{2}$ per cent.

As the amount of P_2O_5 present in the percolate could be determined with considerable accuracy, the amounts in deficit must have been held in the columns of soil and, accordingly for purposes of comparison, it has been distributed amongst the soil sections in proportion to the P_2O_5 held in each section. Although the errors involved are large, the great difference in the character of the results obtained from the two types of soil is so distinct that it does not affect the validity of the conclusions drawn. The results obtained are given in Tables XIV and XV.

TABLE XIV.

Showing the results obtained from the percolation of superphosphate solution through Pusa and Kalianpur soils.

Section	P_2O_5 present in solution	P_2O_5 present in insoluble form	P_2O_5 present originally in soil	P_2O_5 retained by soil	Total P_2O_5 held in section	REMARKS	Corrected value for total P_2O_5 held in section	Per cent. of original P_2O_5 held in section
PUSA SOIL. (dry)								
0"-2"	0.0291	0.7409	0.0404	0.7005	0.7296	Percolate ..	0.0024	0.8915
2"-4"	0.0192	0.1208	"	0.0804	0.0996	Soil solution ..	0.1319	0.1217
4"-6"	0.0176	0.0882	"	0.0478	0.0654	Retained ..	0.9632	0.0799
6"-8"	0.0150	0.0759	"	0.0355	0.0505			0.0617
8"-10"	0.0139	0.0741	"	0.0337	0.0476	Total ..	1.0975	0.0583
10"-12"	0.0115	0.0723	"	0.0319	0.0434	P_2O_5 taken ..	1.3408	0.0530
12"-14"	0.0089	0.0503	"	0.0099	0.0188	Error for distri-		0.0230
14"-16"	0.0071	0.0529	"	0.0125	0.0196	bution ..	0.2433	0.0240
16"-18"	0.0055	0.0428	"	0.0024	0.0079			0.0097
18"-20"	0.0041	0.0490	"	0.0086	0.0127			0.0156
Total	0.1319	1.3672	0.4040	0.9632	1.0951	....	1.3384	

TABLE XIV.—*contd.*

Section	P ₂ O ₅ present in solution	P ₂ O ₅ present in insoluble form	P ₂ O ₅ present originally in soil	P ₂ O ₅ retained by soil	Total P ₂ O ₅ held in section	REMARKS	Corrected value for total P ₂ O ₅ held in section	Per cent. of original P ₂ O ₅ held in section
PUSA SOIL (moist)						gm. P ₂ O ₅		
0"- 2"	0.0143	0.3418	0.0178	0.3240	0.3383		0.3764	73.7
2"- 4"	0.0084	0.0496	"	0.0318	0.0402	Percolate .. 0.0000	0.0447	8.8
4"- 6"	0.0053	0.0342	"	0.0164	0.0217	Soil solution .. 0.0399	0.0241	4.7
6"- 8"	0.0046	0.0340	"	0.0162	0.0208	Retained .. 0.4190	0.0231	4.5
8"-10"	0.0040	0.0313	"	0.0135	0.0175	Total .. 0.4589	0.0196	3.8
10"-12"	0.0030	0.0296	"	0.0118	0.0148	P ₂ O ₅ taken .. 0.5106	0.0165	3.2
12"-14"	0.0003	0.0199	"	0.0021	0.0024	Error for distribution .. 0.0517	0.0027	0.5
14"-16"	nil	0.0190	"	0.0012	0.0012		0.0013	0.25
16"-18"	nil	0.0188	"	0.0010	0.0010		0.0011	0.2
18"-20"	nil	0.0188	"	0.0010	0.0010		0.0011	0.2
Total	0.0399	0.5970	0.1780	0.4190	0.4589		0.5106	
KALIANPUR SOIL (dry)						gm. P ₂ O ₅		
0"- 2"	0.0375	0.1447	0.0754	0.0693	0.1068		0.1312	16.5
2"- 4"	0.0254	0.1332	"	0.0578	0.0832	Percolate .. 0.0348	0.1022	12.9
4"- 6"	0.0249	0.1389	"	0.0635	0.0884	Soil solution .. 0.2215	0.1086	13.7
6"- 8"	0.0221	0.1217	"	0.0463	0.0684	Retained .. 0.3963	0.0840	10.6
8"-10"	0.0199	0.1169	"	0.0415	0.0614	Total .. 0.6526	0.0754	9.5
10"-12"	0.0218	0.1063	"	0.0309	0.0527	P ₂ O ₅ taken .. 0.7938	0.0647	8.2
12"-14"	0.0205	0.1094	"	0.0340	0.0545	Error for distribution .. 0.1412	0.0670	8.4
14"-16"	0.0181	0.0975	"	0.0221	0.0402		0.0494	6.2
16"-18"	0.0163	0.0913	"	0.0159	0.0322		0.0396	5.0
18"-20"	0.0150	0.0904	"	0.0150	0.0300		0.0369	4.6
Total	0.2215	1.1503	0.7540	0.3963	0.6178		0.7590	

TABLE XIV.—*concl'd.*

Section	P ₂ O ₅ present in solution	P ₂ O ₅ present in insoluble form	P ₂ O ₅ present originally in soil	P ₂ O ₅ retained by soil	Total P ₂ O ₅ held in section	REMARKS	Corrected value for total P ₂ O ₅ held in section	Per cent. of original P ₂ O ₅ held in section
KALIANPUR SOIL (moist)						gram. P ₂ O ₅		
0"-2"	0.0359	0.1632	0.0731	0.0901	0.1260		0.1541	19.3
2"-4"	0.0318	0.1508	"	0.0777	0.1095	Percolate ..	0.0008	16.7
4"-6"	0.0271	0.1261	"	0.0530	0.0801	Soil solution ..	0.2220	12.3
6"-8"	0.0254	0.1208	"	0.0477	0.0731	Retained ..	0.4306	11.2
8"-10"	0.0221	0.1054	"	0.0323	0.0544			8.3
10"-12"	0.0207	0.1050	"	0.0319	0.0526	Total ..	0.6534	8.0
12"-14"	0.0201	0.1019	"	0.0288	0.0489	P ₂ O ₅ taken ..	0.7991	7.5
14"-16"	0.0168	0.1006	"	0.0275	0.0443	Error for distribution ..	0.1457	6.8
16"-18"	0.0124	0.0983	"	0.0252	0.0376			5.7
18"-20"	0.0097	0.0895	"	0.0164	0.0261			4.0
Total	0.2220	1.1616	0.7310	0.4306	0.6526		0.7983	

TABLE XV.

Showing results obtained when only the total P₂O₅ held in each section is determined.

Section	P ₂ O ₅ present in each section	P ₂ O ₅ originally present in soil	P ₂ O ₅ held in each section	REMARKS	Corrected value for P ₂ O ₅ held in each section	Per cent. of P ₂ O ₅ taken held in each section
PUSA SOIL				gram. P ₂ O ₅		
0"-2"	0.5495	0.0194	0.5301	Percolate ..	0.0049	69.8
2"-4"	0.0732	"	0.0538	P ₂ O ₅ retained in sections ..	0.7578	7.1
4"-6"	0.0591	"	0.0397			5.2
6"-8"	0.0547	"	0.0353			4.6
8"-10"	0.0468	"	0.0274	Total ..	0.7627	3.6
10"-12"	0.0397	"	0.0203	P ₂ O ₅ taken ..	0.7938	2.7
12"-14"	0.0344	"	0.0150			2.0
14"-16"	0.0318	"	0.0124	Error ..	0.0311	1.6
16"-18"	0.0300	"	0.0106			1.4
18"-20"	0.0326	"	0.0132			1.7
Total	0.9518	0.1940	0.7578		0.7889	

TABLE XV.—*concl.*

Section	P ₂ O ₅ present in each section	P ₂ O ₅ originally present in soil	P ₂ O ₅ held in each section	REMARKS	Corrected value for P ₂ O ₅ held in each section	Per cent. of P ₂ O ₅ taken held in each section
KALIANPUR SOIL						
0"-2"	0.1535	0.0343	0.1192	Percolate ..	0.0271	0.1318
2"-4"	0.1561	"	0.1218	P ₂ O ₅ retained		0.1344
4"-6"	0.1270	"	0.0927	in sections..	0.6942	0.1024
6"-8"	0.1164	"	0.0821			0.0907
8"-10"	0.1058	"	0.0715	Total ..	0.7213	0.0790
10"-12"	0.0820	"	0.0477	P ₂ O ₅ taken ..	0.7938	0.0527
12"-14"	0.0820	"	0.0477			0.0527
14"-16"	0.0759	"	0.0416	Error ..	0.0725	0.0459
16"-18"	0.0706	"	0.0363			0.0400
18"-20"	0.0679	"	0.0336			0.0371
Total	1.0372	0.3430	0.6942			0.7667

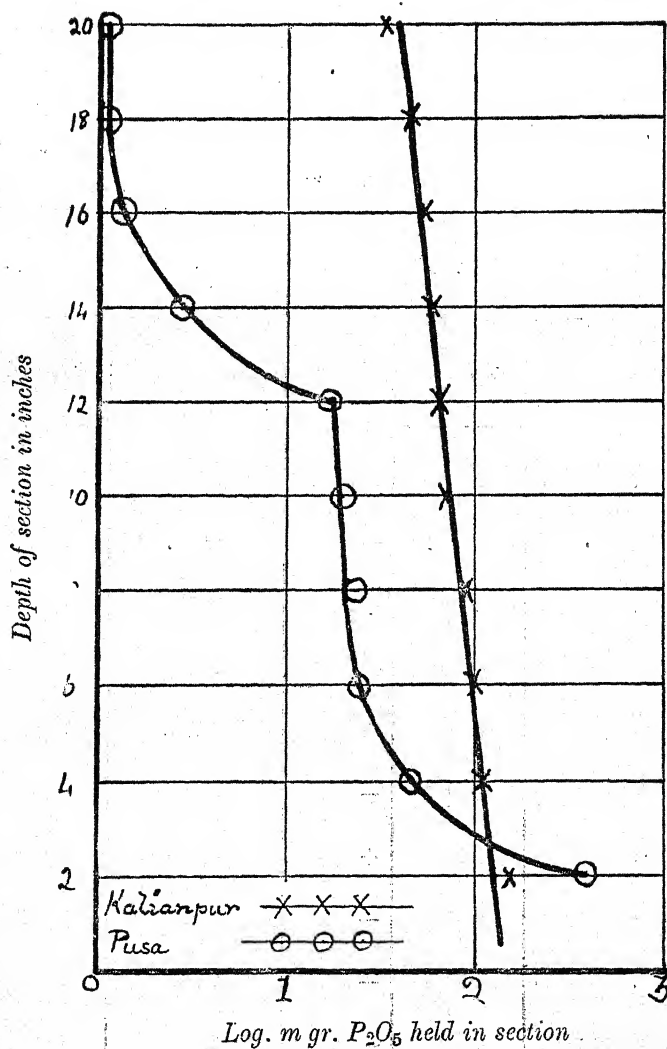
That the cause of the retention of superphosphate and the consequent range of action of the latter in the two soils is clearly demonstrated by these results. In the first place the amount of P₂O₅ which is retained in each successive layer of the Pusa soil decreases very rapidly until the 12"—14" layer is reached when the retention is practically completed, and the percolates contain either none or only very small amounts of P₂O₅. Furthermore, of the total P₂O₅ held by each section 67 to 74 per cent. is held in the first two inches, and 76 to 83 per cent. in the first four inches.

On the other hand, the Kalianpur soil shows no break in continuity throughout the whole depth of the soil; the percolate contains as much as 27 per cent. of the P₂O₅ originally taken, the first layer of the soil only retains 17 to 19 per cent. of P₂O₅, and the first four inches only retains 29 to 36 per cent.

These differences are made more pronounced when a detailed study of the values obtained is made. Taking the case of the Kalianpur soil first it is found that if the logarithm of the total value for the P₂O₅ held in any section, *i.e.*, the sum of the soluble and the retained P₂O₅, is plotted against the depth, the points lie about a straight line, whereas in the case of the Pusa soil the points lie on a curve broken at the 12"—14" section. The curves obtained for the "moist" soils are given in Diagram VI.

DIAGRAM VI.

Showing curves produced on plotting log total m.gr. P_2O_5 held in each section against the depth.



Consequently the relationship—

$\log T = a - kd$ holds good for the Kaliaanpur soil,
 where T = m.gr. total P_2O_5 held in a section,

d =depth of the section in inches,
and a and k are constants.

It will be found that the values $a=2.18$ and $k=0.0303$ fit the results very closely in the case of the dry soil, and $a=2.28$ and $k=0.0385$ hold for the moist soil. The following table contrasts the calculated and the experimental values.

TABLE XVI.

Showing the calculated and the experimental values obtained for the total quantity of P_2O_5 held in each section.

KALIANPUR SOIL (dry):				KALIANPUR SOIL (moist)		
d	T calculated	T found	Error	T calculated	T found	Error
2	0.1316	0.1312	— 0.0004	0.1596	0.1541	— 0.0055
4	0.1145	0.1022	— 0.0123	0.1337	0.1339	+ 0.0002
6	0.0996	0.1086	+ 0.0090	0.1119	0.0980	— 0.0139
8	0.0866	0.0840	— 0.0026	0.0938	0.0894	— 0.0044
10	0.0753	0.0754	+ 0.0001	0.0785	0.0666	— 0.0119
12	0.0655	0.0647	— 0.0008	0.0658	0.0644	— 0.0014
14	0.0570	0.0670	+ 0.0100	0.0551	0.0598	+ 0.0047
16	0.0496	0.0494	— 0.0002	0.0461	0.0542	+ 0.0081
18	0.0431	0.0396	— 0.0035	0.0386	0.0460	+ 0.0074
20	0.0375	0.0369	— 0.0006	0.0324	0.0319	— 0.0005

The formula $\log T = a - kd$ can, of course, be put into the exponential form ; $T = Ae^{-kd}$, and consequently the relationship between the concentration

of P_2O_5 and depth follows the ordinary "compound interest" law. In other words, in non-calcareous soils the amount of the P_2O_5 of superphosphate retained in any soil layer, when percolating downwards in the soil solution, diminishes in geometrical proportion as the depth increases in arithmetical proportion, a conclusion which is in accordance with retention by physical agencies.

From the formula $\log T = a - kd$ the total quantity of P_2O_5 in milligrams (H) held in a column of soil down to a depth d can be shown to be equal to $K(1 - a^d)$, where K and a are constants respectively equal to 0.940 and 0.925 in the case of the dry soil, and 0.915 and 0.912 for the moist soil. The following table compares the calculated and the experimental values.

TABLE XVII.

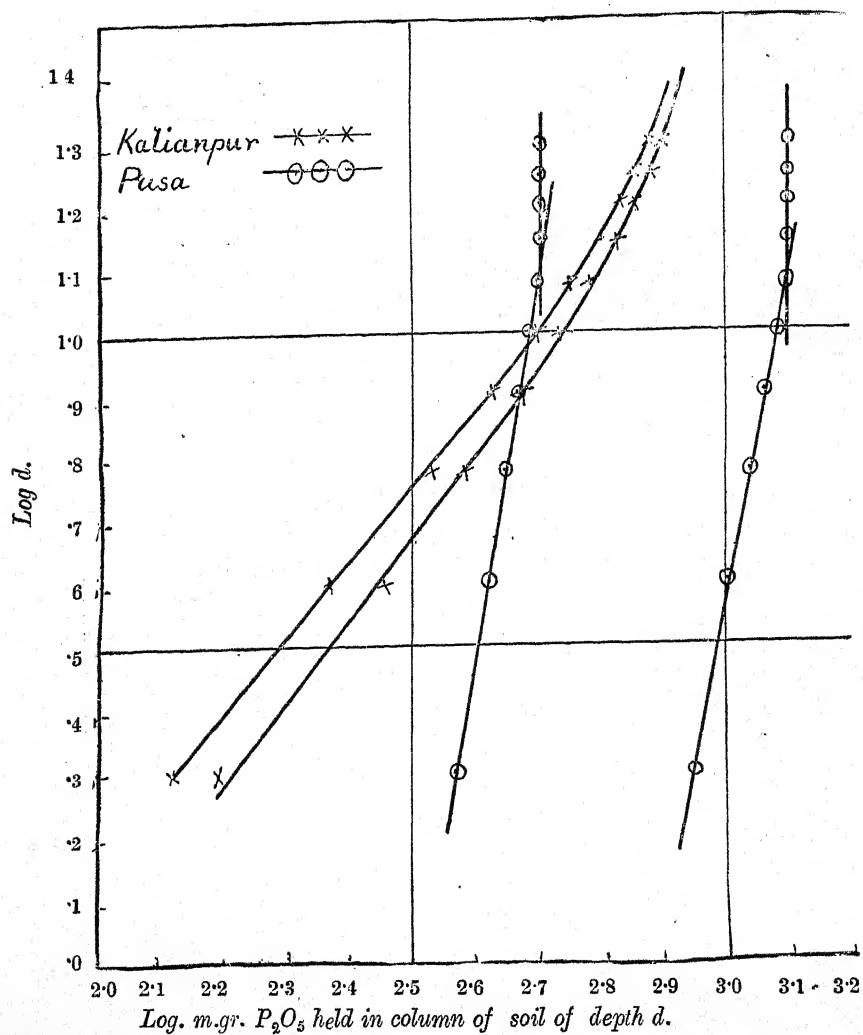
Showing the calculated and the experimental values obtained for the quantity of P_2O_5 held in a column of soil.

Depth of soil column d	KALIANPUR SOIL (dry)			KALIANPUR SOIL (moist)		
	H calculated	H found	Error	H calculated	H found	Error
2	0.1357	0.1312	- 0.0045	0.1540	0.1541	+ 0.0001
4	0.2518	0.2334	- 0.0184	0.2820	0.2880	+ 0.0060
6	0.3512	0.3420	- 0.0092	0.3886	0.3860	- 0.0026
8	0.4362	0.4260	- 0.0102	0.4771	0.4754	- 0.0017
10	0.5089	0.5014	- 0.0075	0.5508	0.5420	- 0.0088
12	0.5712	0.5661	- 0.0051	0.6121	0.6064	- 0.0057
14	0.6244	0.6331	+ 0.0087	0.6631	0.6662	+ 0.0031
16	0.6700	0.6825	+ 0.0125	0.7055	0.7204	+ 0.0149
18	0.7090	0.7221	+ 0.0131	0.7407	0.7664	+ 0.0257
20	0.7423	0.7590	+ 0.0167	0.7700	0.7983	+ 0.0283

Turning now to the results from the Pusa soils it will be found that when the logarithm of the total P_2O_5 in milligrams held in a column of soil is plotted against the log of the depth of the column, a straight line results up to 12 inches depth. Above that depth the curve is broken and the phenomenon of retention may be taken as ceasing at that point,

DIAGRAM VII.

Showing curves produced on plotting log total P_2O_5 (m.gr.) held in column of soil against log depth of column.



Therefore $\log H = A + B \log d$,

where d = column of soil in inches,

H = m.gr. P_2O_5 held in column d ,

and A and B are constants equal to 2.5271

and 0.16 respectively for the moist soil,

and 2.893 and 0.194 for the dry soil.

The calculated and the experimental values are contrasted in the following table.

TABLE XVIII.

Showing the calculated and the experimental values obtained for the quantity of P_2O_5 held in a column of soil.

Depth of soil	MOIST			DRY		
	P_2O_5 present	P_2O_5 calculated	Error	P_2O_5 present	P_2O_5 calculated	Error
0"- 2"	0.3764	0.3761	- 0.0003	0.8915	0.8916	+ 0.0001
0"- 4"	0.4211	0.4201	- 0.0010	1.0132	1.0170	+ 0.0038
0"- 6"	0.4452	0.4483	+ 0.0031	1.0931	1.0985	+ 0.0054
0"- 8"	0.4683	0.4695	+ 0.0012	1.1548	1.1600	+ 0.0052
0"-10"	0.4879	0.4865	- 0.0014	1.2131	1.2110	- 0.0021
0"-12"	0.5044	0.5010	- 0.0034	1.2661	1.2530	- 0.0131
0"-14"	0.5071	0.5134	+ 0.0063	1.2891	1.2910	+ 0.0019
0"-16"	0.5084	0.5246	+ 0.0162	1.3131	1.3240	+ 0.0109
0"-18"	0.5095	0.5344	+ 0.0249	1.3228	1.3540	+ 0.0312
0"-20"	0.5106	0.5436	+ 0.0330	1.3384	1.3810	+ 0.0426

From the general formula $\log H = A + k \log d$, or $H = ad^k$ for the total P_2O_5 held in a column of soil, the amount of P_2O_5 held in any section can be deduced.

Let T = the amount of P_2O_5 in m.gr. held in a section at depth d .

Then $T = P_2O_5$ in column $d - P_2O_5$ in column $(d-2)$

$$= ad^k - a(d-2)^k$$

$$= a\{d^k - (d-2)^k\}$$

For the moist soil $a = 336.6$ and $k = 0.16$, and for the dry soil $a = 781.6$ and $k = 0.194$. The following table shows the calculated and the experimental values for the sections.

TABLE XIX.

Showing the calculated and the experimental values obtained for the quantity of P_2O_5 held in section.

Section	DRY SOIL			MOIST SOIL		
	Found	Calculated	Error	Found	Calculated	Error
0"- 2"	0.8915	0.8916	- 0.0001	0.3764	0.3761	+ 0.0003
2"- 4"	0.1217	0.1259	- 0.0042	0.0447	0.0438	+ 0.0009
4"- 6"	0.0799	0.0813	- 0.0014	0.0241	0.0283	- 0.0042
6"- 8"	0.0617	0.0618	- 0.0001	0.0231	0.0212	+ 0.0019
8"-10"	0.0583	0.0500	+ 0.0083	0.0196	0.0172	+ 0.0024
10"-12"	0.0530	0.0422	+ 0.0108	0.0165	0.0141	+ 0.0024
12"-14"	0.0230	0.0375	- 0.0145	0.0027	0.0125	- 0.0098
14"-16"	0.0240	0.0336	0.0096	0.0013	0.0111	- 0.0098
16"-18"	0.0097	0.0297	- 0.0200	0.0011	0.0101	- 0.0090
18"-20"	0.0156	0.0274	- 0.0118	0.0011	0.0091	- 0.0080

It is evident from the preceding that the distribution of the P_2O_5 through columns of the type soils is regulated by strictly defined laws which, however, are very different in each case.

In the case of the Kalianpur soil the regulating expression is $\log T = a - kd$, which works out to $T = \frac{151.0}{(1.073)^d}$ in the case of dry soil, and $T = \frac{190.5}{(1.092)^d}$ for moist soils. Consequently as d increases, the amount held in each succeeding section gradually decreases.

With Pusa soil the corresponding regulating expression is $T = a\{d^k - (d-2)^k\}$.

From this it follows that in the first section $T = a \cdot 2^k$, whereas in the second section $T = a(4^k - 2^k)$. As k varies from about $\frac{1}{6}$ to $\frac{1}{3}$, T in the first section is approximately equal to a , but in the second and succeeding sections it is only a small fraction of a . Consequently the major portion of the P_2O_5 is held in the surface section. Further, as d increases, the difference between d^k and $(d-2)^k$ rapidly approaches zero which, in effect, means that the P_2O_5 cannot penetrate in appreciable quantities below a very limited depth.

Thus, in non-calcareous soils the superphosphate tends to distribute itself through the soil in a comparatively uniform manner, whereas in calcareous soils its distribution is restricted and the major portion of it is concentrated in the surface layers.

That this difference in the behaviour of the type soils to superphosphate is determined by the CaCO_3 content of the soil is readily demonstrated by instituting percolation experiments with the Kalianpur soil with which a proportion of finely divided CaCO_3 has been intimately mixed.

Distribution of P_2O_5 through a mixture of the Kalianpur soil with 5 per cent. CaCO_3 . A percolation experiment was carried out in a similar manner to the preceding with the Kalianpur soil to which 5 per cent. of CaCO_3 had been intimately mixed. The experimental values obtained were as follows:—

TABLE XX.

Showing distribution of P_2O_5 through a mixture of Kalianpur soil with 5 per cent. CaCO_3 .

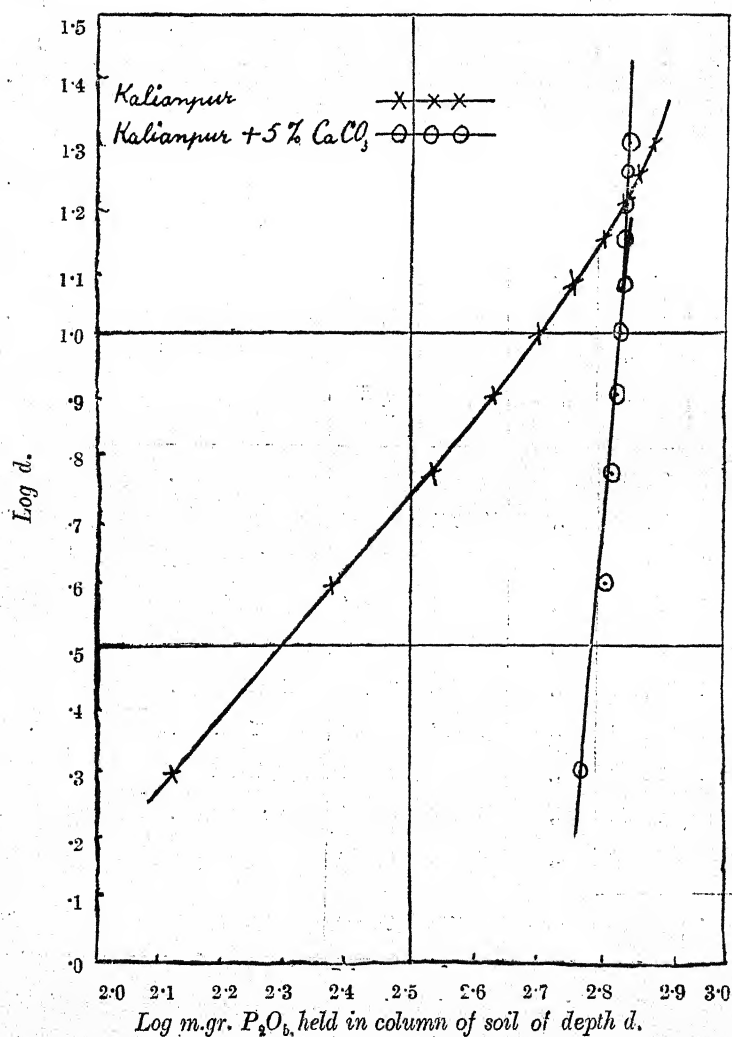
Section	P_2O_5 present in solution	Total insoluble P_2O_5	P_2O_5 originally present in the soil	P_2O_5 retained by soil	Total P_2O_5 held in section	REMARKS	CORRECTED VALUES	
							Total P_2O_5 in held each section T	Per cent. of original P_2O_5 held by soil in each section
0"- 2"	0.0224	0.6068	0.0589	0.5479	0.5703	gram.	0.5987	86.4
2"- 4"	0.0043	0.0953	"	0.0364	0.0407	P_2O_5	0.0427	6.2
4"- 6"	0.0027	0.0697	"	0.0108	0.0135	Percolate ..	0.0142	2.0
6"- 8"	0.0026	0.0657	"	0.0068	0.0094	Retained by soil	0.0099	1.4
8"-10"	0.0028	0.0653	"	0.0064	0.0092	Present in solu-	0.0097	1.4
10"-12"	0.0024	0.0617	"	0.0028	0.0052	tion ..	0.0055	0.8
12"-14"	0.0018	0.0613	"	0.0024	0.0042	Total ..	0.0044	0.6
14"-16"	0.0011	0.0609	"	0.0020	0.0031	P_2O_5 taken ..	0.0033	0.5
16"-18"	traces	0.0613	"	0.0024	0.0024	Error ..	0.0025	0.4
18"-20"	traces	0.0609	"	0.0020	0.0020		0.0021	0.3
Total	0.0401	1.2089	0.5890	0.6199	0.6600		0.6930	

A comparison of these results with those given in Tables XIV and XV shows that by the addition of 5 per cent. CaCO_3 to the Kalianpur soil the

character of the retention has been changed and brought into line with that of the Pusa soil. This is clearly brought out in the following diagram where the $\log (P_2O_5 \text{ held in column of soil of depth } d)$, i.e., $\log H$ is plotted against $\log d$ for the Kalianpur soil, and the Kalianpur soil plus 5 per cent. $CaCO_3$.

DIAGRAM VIII.

Showing curves produced on plotting \log total P_2O_5 (m.gr.) held in column of soil against \log depth of column.



The fact that the addition of CaCO_3 to Kalianpur soil causes the retention and distribution of P_2O_5 through the soil to assume the characteristics of the Pusa soil, demonstrates clearly that it is the cause of the retention in calcareous soils and that the retention of superphosphate in these soils is due to the formation of more insoluble calcium phosphates as distinct from the physical retention in non-calcareous soils.

The position attained from a comparison of the results of these percolation experiments may be summarized as follows :—

1. The distribution of superphosphate through a non-calcareous soil by percolation is of a uniform type and is a function of the depth of percolation. The P_2O_5 penetrates to a considerable depth in accordance with the laws of adsorption, and consequently the effect of applications of superphosphate to such soils is widespread.

2. The distribution in the case of calcareous soils is of a non-uniform type the major portion of the P_2O_5 being held in the top layers of soil. Consequently the application of superphosphate to these soils has a very restricted effect and has therefore probably much less efficiency than equivalent amounts applied to soils of the opposite type.

3. In proportion to the amount of superphosphate applied to the columns of soil, the soil solution of calcareous soils contains a much less concentration of P_2O_5 than in the case of non-calcareous soils. In the light of present knowledge this can only mean that the P_2O_5 retained is in a much more available form in the latter soils.

4. That carbonate of lime is the main factor in determining the range of action and distribution of P_2O_5 in the soil is shown by the fact that when CaCO_3 is added to a non-calcareous soil, the experimental results then conform to the type found in calcareous soils. The retention of superphosphate in the latter is of a chemical nature due to the formation of insoluble calcium phosphates, and distinct from the physical retention of non-calcareous soils.

This being the case, it would seem very probable that if soluble phosphates, which have little or no chemical reaction with CaCO_3 , were applied to calcareous soils, then the distribution of P_2O_5 would be mainly due to adsorption, and would be of a much more uniform type, resulting in increased efficiency. To test this point, a percolation experiment was carried out with a solution of di-sodium phosphate and Pusa soil. The results obtained were as follows :—

TABLE XXI.

Showing the results obtained from the percolation of di-sodium phosphate solution through Pusa soil.

Section	P_2O_5 present, in solution	Total insoluble P_2O_5	P_2O_5 originally present in the soil	P_2O_5 retained by soil	Soluble and insoluble P_2O_5 held in section	REMARKS	CORRECTED VALUES	
							Total P_2O_5 held in each section	Per cent. of original P_2O_5 held in each section
0"-2"	0.0243	0.1861	0.0192	0.1669	0.1912	Percolate .. ^{gm.} P_2O_5 0.0019	0.2084	29.1
2"-4"	0.0247	0.0498	"	0.0306	0.0553		0.0602	8.4
4"-6"	0.0273	0.0507	"	0.0315	0.0588	P_2O_5 in solution 0.2786	0.0641	8.9
6"-8"	0.0293	0.0494	"	0.0302	0.0595		0.0649	9.0
8"-10"	0.0315	0.0503	"	0.0311	0.0626	P_2O_5 insoluble . 0.3800	0.0682	9.5
10"-12"	0.0324	0.0476	"	0.0284	0.0608		0.0663	9.1
12"-14"	0.0293	0.0406	"	0.0214	0.0507	Total .. 0.6605	0.0553	7.7
14"-16"	0.0302	0.0326	"	0.0134	0.0436	P_2O_5 taken .. 0.7197	0.0475	6.6
16"-18"	0.0278	0.0362	"	0.0170	0.0448		0.0488	6.8
18"-20"	0.0218	0.0287	"	0.0095	0.0313	Error .. 0.0592	0.0341	4.7
Total	0.2786	0.5720	0.1920	0.3800	0.6586		* 0.7178	

The results are not strictly parallel to any obtained before, but they conform more nearly to the type of distribution found with the Kalianpur soil than with the Pusa soil, when superphosphate was used:—

1. A comparatively small amount of P_2O_5 is retained by the first section of soil and the retained P_2O_5 is distributed more uniformly through the column of soil than was the case with superphosphate.

2. The amount of P_2O_5 in solution in each section is high and is fairly uniformly distributed.

3. The soluble P_2O_5 percolates to the deep layers and is there found in a comparatively high concentration.

It is, therefore, evident, that by using dressings of soluble phosphates, which have little or no reaction with $CaCO_3$, in place of superphosphate on calcareous soils, a much more uniform distribution of the P_2O_5 throughout the soil can be attained.

Provided that these phosphates are suitable for plant food, this wider distribution can only result in a wider and deeper root action and better cropping in such soils.

SUMMARY AND GENERAL CONCLUSIONS.

1. Retention of the P_2O_5 of superphosphate only occurs through adsorption in soils which are practically devoid of $CaCO_3$ or other substances capable of reacting with the acid salt. In presence of the latter the retention is due almost entirely to chemical combination resulting in the formation of comparatively insoluble compounds.

2. Generally, the first combination formed is that of di-calcic phosphate, $CaHPO_4$, and this reaction takes place very rapidly. Afterwards the di-calcic phosphate slowly reacts with more $CaCO_3$ forming tri-calcic phosphate, $Ca_3(PO_4)_2$.

3. As the reaction between superphosphate and $CaCO_3$ is very rapid, the range of action of the former is very limited. Further, the reaction between $CaCO_3$ and *dissolved* $CaHPO_4$ is again very rapid so that even this secondary reaction is very localized.

4. The very localized action of superphosphate in calcareous soils is demonstrated by percolation experiments in which it is shown that most of the P_2O_5 is retained in the surface layers. On the other hand, in non-calcareous soils penetration of the P_2O_5 takes place in appreciable quantity into the deep layers. The addition of a small quantity of $CaCO_3$ to a non-calcareous soil brings about a distribution of P_2O_5 analogous to that in calcareous soils showing that $CaCO_3$ is the determining agent.

5. It has been shown that even in calcareous soils the retention of the P_2O_5 of soluble phosphates having a neutral or alkaline reaction (*e.g.*, the phosphates of soda) is due to adsorption, and percolation experiments with such soils and phosphates show that a very even distribution of P_2O_5 can be attained. It would, therefore, seem very probable that such phosphates would be more efficacious than superphosphate in calcareous soils. This point is under investigation.

6. The phosphate manuring of calcareous soils is obviously a very different problem to that of non-calcareous soils and requires special study.

7. Although $CaHPO_4$ is formed in the first instance when superphosphate is applied to calcareous soils, the amount of P_2O_5 held in the soil solution does

not depend upon the solubility of this substance, but rather upon the proportion of Ca-ions in the solution, the presence of which reduces the amount of P_2O_5 in solution very considerably. Consequently manuring with superphosphate is relatively much more inefficient in calcareous than in non-calcareous soils.

WINDROWING SUGARCANE IN THE NORTH- WEST FRONTIER PROVINCE.

PART I.

THE EFFECT ON THE ECONOMICAL AND AGRICULTURAL SITUATION.

BY

W. ROBERTSON BROWN,

Agricultural Officer, North-West Frontier Province.

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WINDROWING is the term which has been adopted by the sugar-planters of Louisiana to describe their own method of preserving sugarcane from rapid deterioration after the leaves and buds of the cane have been killed by frost. In the American cane-sugar state, the mercury falls to 22-26°F. on one or more occasions in the course of almost every manufacturing season. Yet Louisiana produces over 200,000 tons of white sugar a year. In the sugarcane area of the North-West Frontier Province the mercury does not often drop below 28°F., and cane for the production of *gur* is not injured by four or five degrees of frost. But if the manufacture of white sugar is undertaken at Peshawar, it is possible that occasions might arise when windrowing would have to be done. A study of the American practice was therefore undertaken at the Peshawar Agricultural Station, and cane was first windrowed there in 1916.

Four seasons are recognized in the Peshawar valley : Spring in February, March and April. During the earlier part of this season there are occasionally light hailstorms, and, usually, rain falls to the extent of three or four

inches. Normals of temperature, derived from the data of 33 years, are as follows :—

Month	Normal maximum temperature	Normal minimum temperature	Normal mean temperature
	°F	°F	°F
February ..	65.7	42.5	54.1
March ..	75.0	51.7	63.3
April ..	85.5	60.3	72.9

Summer in May, June and July. Rain rarely falls during this season which is the hottest of the year. Normals of temperature are as follows :—

Month	Normal maximum temperature	Normal minimum temperature	Normal mean temperature
	°F	°F	°F
May ..	98.1	69.9	54.0
June ..	105.9	77.3	91.6
July ..	102.7	79.2	90.9

Autumn in August, September and October. The season is ushered in by the hot weather rains. They break over the valley in four or five violent storms at intervals of a few days, and two or three inches of rainfall on each occasion. During the first part of this season the sky is more or less overcast with clouds and the air is steamy and oppressive. Normals of temperature are as follows :—

Month	Normal maximum temperature	Normal minimum temperature	Normal mean temperature
	°F	°F	°F
August	99.2	78.0	88.6
September	95.6	70.5	83.1
October	88.2	57.9	73.1

Winter in November, December and January. During this season the weather is variable. The sky is at first hazy, then cloudy, with sometimes slight rain. There is a remarkable absence of wind generally, and the air is still and stagnant. The first touch of frost is expected towards the end of November. The mercury sometimes drops to 26°F., but usually not more than two or three degrees of frost is registered. Normals of temperature are as follows:—

Month		Normal maximum temperature	Normal minimum temperature	Normal mean temperature
		°F	°F	°F
November	..	77.3	46.1	61.7
December	..	69.0	39.2	53.1
January	..	63.0	39.6	51.3

As the average annual rainfall is only about 14 inches, sugarcane is irrigated from 20 to 25 times during the period of its growth, which extends from April to the end of October.

Although sugarcane is known to have been cultivated in the valley for nearly a thousand years, only one variety is now grown on the area of 28,000 acres that is under the crop. It was introduced into the province more than fifty years ago, and it does not appear to have deteriorated in that time. It is a thick, soft, light-green and very juicy *Pounda* variety, yielding, under good cultivation, from 28 to 30 tons stripped cane per acre. Ratooning is not practised at Peshawar, the cultivators having found "plant" cane better and more profitable for *gur*.

The fields are planted in March, and increase in the weight of the cane ceases with the advent of the cold weather in late November. By the middle of December the cane fields are no longer green—the cane tops have been killed by frost—the leaves are yellow and dead. Usually, the lower buds of the cane are not killed by frost until some time in January: in a very mild winter these buds may not be injured. Nevertheless, as the buds of the cane are liable to be killed by frost, the growers have long been accustomed to "clamp" a certain amount of their crop to preserve it for seed. "Clamping" consists of digging up the cane with the surface roots, and laying the clumps with their leaves in a heap, which is covered with about four inches of soil. It is done in November, and the cane is perfectly preserved in this way until the time

for planting arrives in March. Outwardly, a cane "clamp" resembles a potato pit.

If a grower has "clamped" more cane than is required to plant his field, the surplus cane is crushed, and, usually, the *gur* made therefrom is not inferior to that produced from cane treated directly from the field. A series of analyses has shown that no deterioration occurs in cane which has been "clamped" from the 15th November to the end of March. But from a manufacturing point of view "clamping" is expensive. It costs fully one anna per maund to pit the cane and to take it out again. It was thought, however, that *if cane deteriorated as little in windrow at Peshawar as it does in "clamp" there, the practice of windrowing might be of considerable advantage to a sugar factory.* Windrowing is not an expensive operation. It consists of cutting the cane and laying it down, unstripped, where it was grown, the leaves forming a thatch which preserves the solid cane from the weather, and, more especially, from frost. A small amount of cane was accordingly windrowed at the Agricultural Station late in November 1916. In February, this cane, after lying exposed to the weather for three months, yielded first class *gur*. This was a surprising result, for almost wherever sugarcane is grown for the production of white sugar, and certainly in all the tropical parts of the so-called sugarcane belt, it is known that cane deteriorates more or less quickly directly it is cut.

From many points of view it would be a great advantage at times if a sugar factory could permit cane to lie in windrow for ten days or a month, with the knowledge that it would not deteriorate.

A scheme of investigations on a liberal scale was planned for 1917-18-19. In Part II of this Memoir the Imperial Agricultural Chemist, who carried out the tests, will state what results he obtained.

PART II.

THE EFFECT ON THE COMPOSITION OF SUGARCANE.

BY

W. H. HARRISON, D.Sc.,
Imperial Agricultural Chemist ;

AND

P. B. SANYAL, M.Sc.,
Assistant to the Imperial Agricultural Chemist.

IN Part I of this Memoir Mr. Robertson Brown has given an account of the effect of the practice of windrowing sugarcane in the North-West Frontier Province on the economical and agricultural situation, and in this part we propose to deal solely with the changes which occur in the windrowed canes from the point of view of the conservation of their sugar content.

On December 5th, 1917, a large average sample was drawn from a stand of the local *Pounda* cane, covering an area of one acre, and a careful analysis of the juice was made. The whole of the cane was windrowed on December 19th and allowed to remain in this condition until April 5th, 1918, when another average sample was drawn and analysed. The composition of these two samples is shown in Table I.

TABLE I.

Showing percentage composition of the juice from local Pounda canes before and after windrowing.

Component	Before windrowing on December 5th	After windrowing on April 5th
Average weight of cane lb. ..	2.39	2.12
Juice percentage ..	75.84	71.70
Sucrose percentage ..	9.57	13.25
Glucose percentage ..	2.38	2.74
Brix (corrected) ..	13.34	18.05
Coefficient of purity ..	71.70	73.41
Crystallizable sugar*	8.06	11.33

* "Crystallizable sugar" has been calculated from the formula $C = S(1.4 - \frac{40}{P})$ when
C = % crystallizable sugar ; S = % sucrose ; and P = purity of juice.

The effect of windrowing has been very marked. The weight of the individual cane (less tops and roots), and the percentage of the juice expressed, have decreased during this period, showing that there has been a drying up of the cane, and, as a consequence, the concentration of solids in the juice has considerably increased. The percentage of glucose has increased only to a slight extent, whereas that of the sucrose shows a very material increase. This is reflected in the fact that the coefficient of purity shows a decided increase.

It is therefore evident that the *quality* of the juice has improved and, consequently, the yield of sugar from equal weights of juice would be greater after the period of windrowing. Although the juice has not deteriorated it does not follow, however, that there has been no destruction of the sugars originally present in the cane, and this point can only be determined by comparison of the estimates of the sugars present in a given quantity of cane before and after windrowing. This comparison is made in Table II.

TABLE II.

Showing weights of juice, sucrose and glucose in 1,000 lb. of cane at windrowing and the equivalent weight after windrowing.

	Equivalent weight of cane lb.	Weight of juice lb.	Weight of sucrose lb.	Weight of glucose lb.	% GAIN OR LOSS		Crystallizable sugar lb.	% loss or gain of crystallizable sugar
					sucrose	glucose		
Before windrowing ..	1,000	758.4	72.6	18.0	..	..	61.2	..
In March 1918..	887	636.0	84.3	17.4	+16.1	--3.3	72.1	+17.8

Thus not only is the quality of the juice higher after the period of windrowing but, in addition, the weight of sucrose and crystallizable sugar in the crop has been materially increased. This conclusion receives support from the analysis of a number of canes which had been allowed to remain in the ground throughout the cold season and which were analysed early in March. The comparison between the composition of these canes, those analysed in December and the windrowed canes in March, is set out in Tables III & IV.

TABLE III.

Showing the percentage composition of the juice of canes left in the field throughout the cold season until March 1918.

Average weight of cane lb.	..	..	2.62
Percentage juice expressed	..	..	77.86
Percent. sucrose	..	..	11.03
Percent. glucose	..	..	2.35
Brix (corrected)	..	..	15.26
Coefficient of purity	..	..	72.30
% crystallizable sugar	..	..	9.40

TABLE IV.

Showing weights of juice, sucrose and glucose in 1,000 lb. of cane left standing until March 1918.

Equivalent weight of cane lb.	..	..	1,096.0
Weight of juice lb.	..	..	853.6
Weight of sucrose lb.	..	..	94.1
Weight of glucose lb.	..	..	20.1
Weight of crystallizable sugar lb.	..	..	80.2
% increase in sucrose	..	..	29.6
% increase in glucose	..	..	11.7
% increase in crystallizable sugar	..	..	32.7

If the values obtained when the cane is left standing throughout the season are taken as representing the maximum attainable under Peshawar conditions then windrowing in December has led to a loss of 9.8 lb. of sucrose and 8.1 lb. crystallizable sugar for every 1,000 lb. of cane standing in December 1917. Consequently it would appear that the best plan would be to leave the canes in the ground as long as possible. This, however, is not practicable owing to the danger of considerable damage occurring through incidence of a "splitting frost."

Just before the windrowed canes were analysed and for several days afterwards there was heavy rain and it was noticeable that canes analysed after this period were inferior to those already considered.

TABLE V.

Showing inferiority of windrowed cane after a period of rain.

Juice			Crop		
Average weight of cane lb.	..	2.00	Equivalent weight of cane lb.	..	837.0
% juice expressed	..	72.00	Weight of juice lb.	..	602.6
% sucrose	..	12.41	Weight of sucrose lb.	..	74.8
% glucose	..	2.83	Weight of glucose lb.	..	17.1
% crystallizable sugar	..	10.50	Weight of crystallizable sugar lb.	..	63.2
Brix (corrected)	..	17.17	% increase in sucrose	..	+ 2.9
Coefficient of purity	..	72.27	Do. glucose	..	+ 5.9
			Do. crystallizable sugar	..	+ 3.3

These differences were at first assigned to errors of sampling, but a similar depreciation in quality was met with in 1919 immediately after a period of heavy rain, and will be referred to in the sequel.

The conclusions which emerge from the experiments of the season 1917-18 are that the windrowing of cane permits of the cane being stored without deterioration during adverse climatic conditions, and is suitable for adoption in the North-West Frontier Province. At the same time it is noticeable that all the buds are killed, so that when it is desired to store cane for seed windrowing proves unsuitable and recourse must be had to clamping. This season's results, so far as they go, point to a very considerable synthesis of sucrose in the windrowed cane and were of such a striking character that it was decided to continue the investigation during the season 1918-19 on a larger scale.

With this object in view the sugarcane area was divided into three portions, the first of which was sampled and analysed on December 18th, 1918, and immediately windrowed. The second portion was sampled, analysed and windrowed on January 10th, 1919, and the third portion treated in a similar manner on February 3rd. It was possible, therefore, to institute comparisons between canes windrowed early and late, and, at the same time, by drawing samples the character of the changes which had occurred in the windrowed cane could be approximately determined at any moment.

Table VI gives the variations in the composition of the juice of the windrowed canes up to March 12th when the experiment was abandoned, and, when the difficulty of taking a number of representative samples from the same bulk of cane over comparatively long periods of time is taken into consideration, the results may be considered as fairly concordant.

TABLE VI.
Variations in the composition of the juice of windrowed canes.

A. CANES WINDROWED ON DECEMBER 18TH, 1918

Date	Days after windrowing	Average weight of cane lb.	% Juice expressed	Brix (corrected)	% Sucrose	% Glucose	Coefficient of purity	Glucose ratio	% Crystallizable sugar	% Non-sugars
Dec. 18th, 1918 ..	0	2.53	73.05	15.30	12.93	1.25	84.51	9.65	11.98	1.12
" 24th " ..	6	2.45	74.49	15.57	13.11	1.29	84.20	9.81	12.13	1.17
Jany. 1st, 1919 ..	14	2.63	75.24	16.33	13.71	1.36	83.68	9.90	12.66	1.31
" 22nd " ..	35	2.66	75.00	16.66	13.73	1.56	82.42	11.34	12.56	1.37
" 31st " ..	44	2.56	74.61	17.17	13.93	1.57	81.14	12.95	12.61	1.17
Feby. 6th " ..	50	2.32	75.00	17.24	13.97	1.70	81.07	12.14	12.67	1.57
" 20th " ..	64	2.14	73.39	17.91	14.28	2.02	79.73	14.17	12.82	1.61
March 12th " ..	84	2.14	70.56	18.63	14.29	2.21	76.72	15.47	12.57	2.13

TABLE VI—*concl'd.*

B. CANES WINDROWED ON JANUARY 10TH, 1919

Date	Days after windrowing	Average weight of cane lb.	% Juice expressed	Brix (corrected)	% Sucrose	% Glucose	Coefficient of purity.	Glucose ratio	% Crystallizable sugar	% Non-sugars
Jany. 10th, 1919 ..	0	2.25	74.43	15.23	13.11	1.23	86.08	9.32	12.26	0.89
" 16th " ..	6	2.31	72.22	15.74	13.42	1.10	85.25	8.27	12.49	1.22
" 31st " ..	21	2.42	72.52	16.19	13.19	1.25	81.45	9.49	11.98	1.75
Feby. 11th " ..	32	2.24	74.32	16.37	13.47	1.46	82.28	10.83	12.31	1.44
" 20th " ..	41	2.01	71.73	16.16	13.24	1.59	82.01	12.01	12.08	1.33
March 12th " ..	61	1.94	70.36	17.26	13.53	2.03	78.36	15.01	12.55	1.70

C. CANES WINDROWED ON FEBRUARY 3RD, 1919

Feby. 3rd, 1919 ..	0	2.64	76.89	14.95	12.91	1.03	86.36	7.99	12.09	1.01
" 10th " ..	7	2.42	74.68	15.38	13.11	1.03	85.21	7.89	12.20	1.24
" 20th " ..	17	2.24	68.44	15.82	13.23	1.04	83.65	7.86	12.20	1.55
March 3rd " ..	28	2.08	71.50	15.75	13.29	1.24	84.34	8.82	12.30	1.22
" 12th " ..	37	2.08	73.56	15.69	13.17	1.40	83.96	10.65	12.16	1.12

The conclusions which emerge from a comparison of the values given in this table may be summarized as follows:—The total solids present in the juice, as measured by "Brix," increase during the whole period showing that the juice becomes more concentrated as time goes on, and, as this is accompanied by a decrease in weight of an average cane, it may be concluded that evaporation is one factor bringing this change about.

This change in the concentration of the juice is accompanied by increases in the percentages of the sucrose and glucose present, but the proportion of glucose tends to increase in amount more rapidly than the sucrose so that there is a falling off in the quality of the juice. This is clearly shown by the "coefficient of purity" and "glucose ratio" values but, notwithstanding this fact, owing to the increase in the concentration of the juice the variations in the percentage of crystallizable sugar obtainable are practically nil.

It would therefore appear that although windrowing under the Peshawar conditions tends to reduce the purity of the juice, yet, owing to the juice becoming more concentrated, the percentage of crystallizable sugar remains fairly constant and, therefore, *the practice of windrowing will not lead to any appreciable decrease in the amount of sugar obtained from equal weights of juice evaporated.*

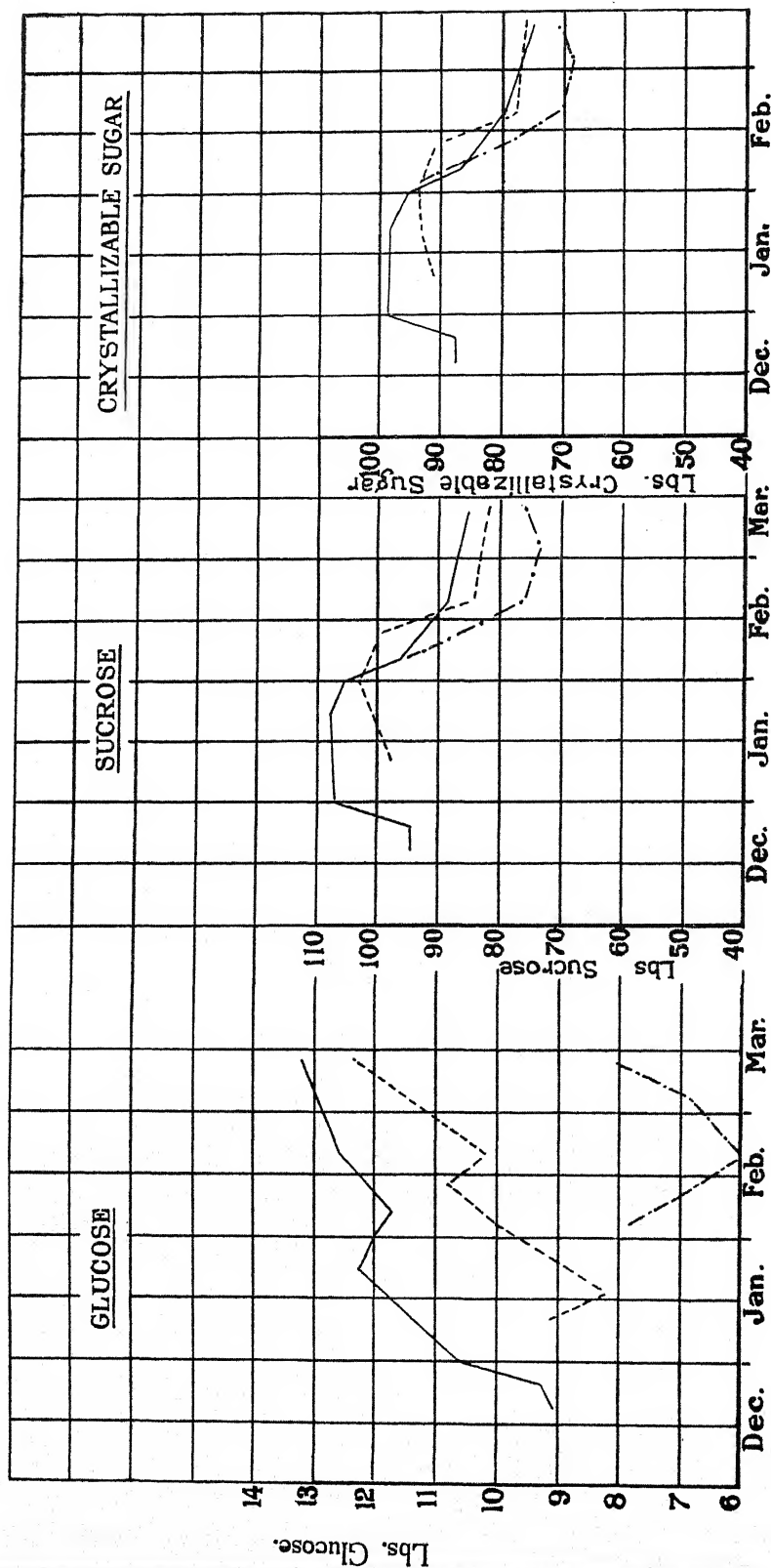
Although windrowing is thus shown to increase the sucrose content of the juice, and not to depress the "crystallizable sugar" value, it does not follow that there is no loss of sucrose and sugar so far as the crop is concerned. This point can only be determined by making careful weighments of the cane taken for the samples and of the juice expressed, and from these figures calculating the values of sucrose, glucose, etc., present in equivalent amounts of cane at the different stages. In Table VII are given the values at the different dates calculated on the basis of the weight of cane equivalent to 1,000 lb. of cane at the time of windrowing.

TABLE VII.

Showing the variations in the amount of sucrose, glucose, etc., per 1,000 lb. of cane at the time of windrowing.

A. CANES WINDROWED ON DECEMBER 18TH, 1918						
Date	Days after windrowing	Equivalent weight of cane lb.	Juice expressed lb.	Sucrose present lb.	Glucose present lb.	Crystallizable sugar present lb.
Decr. 18th, 1918..	0	1,000 0	730.5	94.40	9.13	87.4
" 24th " ..	6	968.5	721.4	94.60	9.31	87.50
Jany. 1st, 1919..	14	1,040.0	782.1	107.20	10.64	99.04
" 22nd " ..	35	1,048.0	785.5	107.90	12.25	98.68
" 31st " ..	44	1,016.0	758.0	105.70	11.98	95.57
Feby. 6th " ..	50	917.0	687.8	96.08	11.69	87.16
" 20th " ..	64	845.8	620.8	88.64	12.54	79.60
March 12th " ..	84	845.8	596.9	85.29	13.19	75.02
B. CANES WINDROWED ON JANUARY 10TH, 1919						
Jany. 10th, 1919..	0	1,000.0	744.3	97.58	9.16	91.26
" 16th " ..	6	1,027.0	741.6	99.59	8.23	92.65
" 31st " ..	21	1,076.0	780.1	102.90	9.75	93.48
Feby. 11th " ..	32	995.4	739.8	99.65	10.80	91.05
" 20th " ..	41	893.4	640.8	84.84	10.19	77.39
March 12th " ..	61	862.2	606.7	82.08	12.32	76.14
C. CANES WINDROWED ON FEBRUARY 3RD, 1919						
Feby. 3rd, 1919..	0	1,000.0	768.9	99.27	7.92	92.94
" 10th " ..	7	916.7	684.6	89.75	7.05	83.54
" 20th " ..	17	848.5	580.7	76.83	6.04	70.84
March 3rd " ..	28	787.9	555.5	73.82	6.89	68.32
" 12th " ..	37	787.9	579.6	76.32	8.11	70.49

Showing the variations in the amounts of Glucose, Sucrose and Crystallizable Sugar present in windrowed Canes.
 Canes windrowed on December 18th 1918 _____ Canes windrowed on January 10th 1919.....Canes
 windrowed on February 3rd 1919 _____



From a comparison of the results in this table it is evident that the amount of sucrose in the *crop* windrowed on December 18th, 1918, increases rapidly up to January 1st and then remains constant throughout that month, after which there is a rapid decrease. The cane windrowed on January 10th shows a similar increase at first and a rapid decrease after the first week of February, whereas the cane windrowed on February 3rd shows a continuous decrease. Thus, it is evident that cane windrowed in December and January more than maintained its sucrose content until early February and after that date both these canes and also those windrowed in February showed a continuous deterioration up to the end of the experiment.

This fluctuation in the quantity of one constituent of the windrowed cane is paralleled by (a) weight of the cane, (b) weight of juice expressed, and (c) is particularly well demonstrated in the case of crystallizable sugar. The only constituent which does not follow the general trend is glucose which, in general, increases in quantity throughout the whole period. These variations are shown graphically in Chart I in the case of sucrose, glucose and crystallizable sugar.

These comparisons clearly show that cane can be stored safely by windrowing under Peshawar conditions for a certain period after which rapid deterioration sets in. The date on which this occurs would appear to be the same whether the cane be windrowed early or late in the season and, consequently, would seem to be due either to biological factor solely connected with the cane, or to a seasonal one which affects all canes in similar degree. In this connection it may be pointed out that, whereas canes windrowed in December 1917 were in perfectly good condition and showed no signs of deterioration four months later, those windrowed in December 1918 and January 1919 could not be kept in good condition beyond the first week of February, and these facts would tend to show that the determining factor is a seasonal one.

This factor, or factors, is not easy of determination unless observations are extended over a series of seasons, but a comparison of the weather records for the season 1917-18 and 1918-19 for Peshawar shows that the mean temperatures from January to March were, in general, slightly lower during 1919 than 1918, and this would appear to throw out of court any question of temperature being the real determining factor which initiates the change. One comparison is, however, significant, and that is the date on which heavy rainfall was experienced. In 1918 no rainfall of any meaning occurred until late in March and the canes were quite good on April 5th, whereas in 1919 one heavy fall was experienced on January 30th and another on February 16th and deterioration was noticeable during early February. Both the temperature and rainfall comparisons are shown in Chart II,

It is possible that the incidence of heavy rainfall is the factor which determines the incidence of deterioration.

SUMMARY.

1. Storage of sugarcane by windrowing can be successfully carried out in the Peshawar valley.
2. Windrowing tends to cause the purity of the juice to deteriorate, but at the same time bring about a concentration of the juice with the result that the amount of "crystallizable sugar" per unit weight of juice remains approximately constant.
3. The weight of sucrose and crystallizable sugar contained in a crop of windrowed cane increases rapidly at first to be followed by a period during which the values remain practically constant, after which deterioration sets in.
4. The period during which canes can be stored varies with different seasons but in any particular season appears to be determined by the incidence of heavy rain.

CHART II.

Rainfall and variation of the mean Weekly Temperature.

